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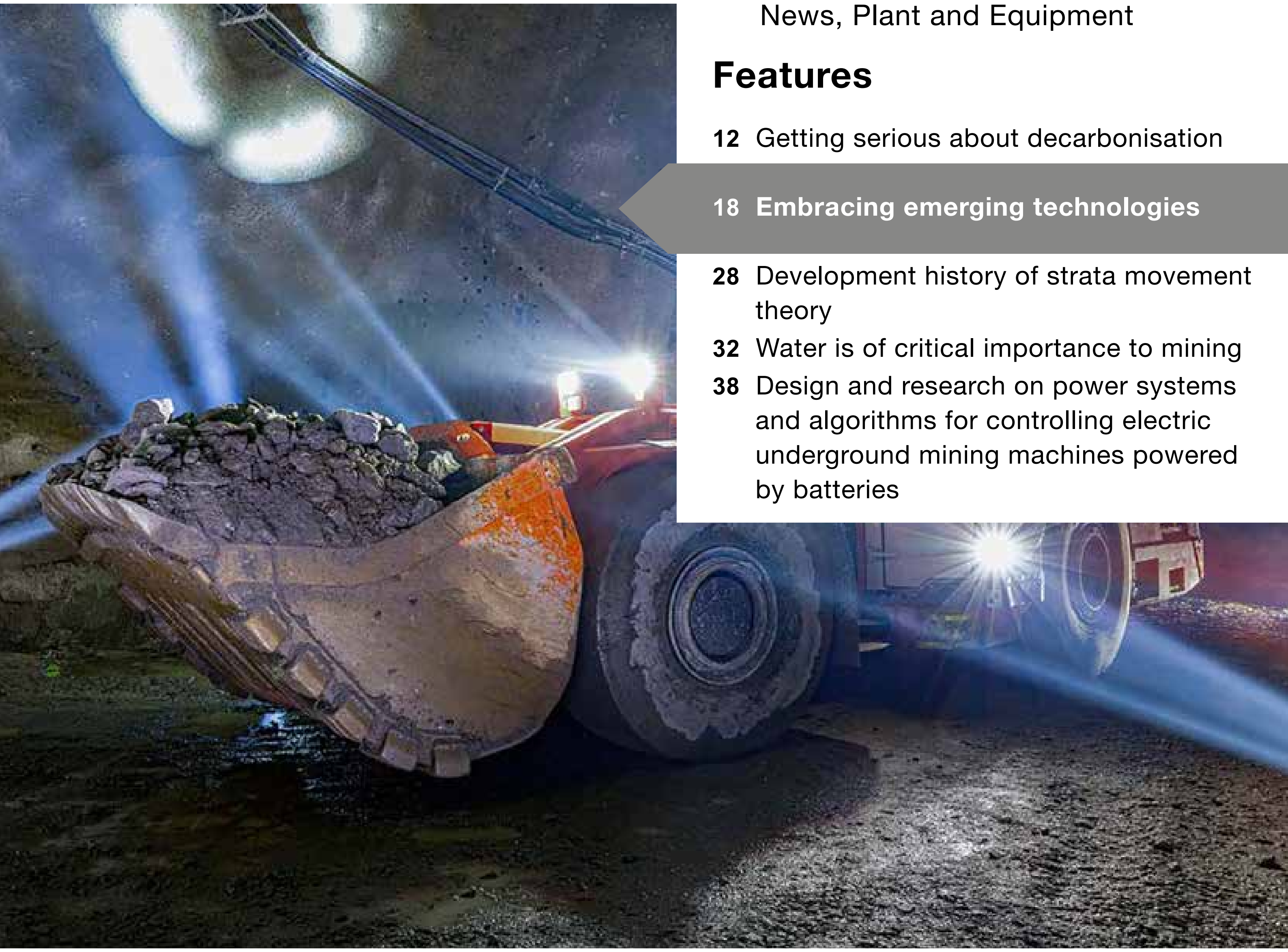

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MC Mining's Uitkomst Colliery increases quarterly output following turnaround plan

Run-of-mine (RoM) coal production at MC Mining's Uitkomst steelmaking and thermal coal mine, in South Africa, increased by 14% year-on-year to 115 909 t for the quarter ended March 31 – the third quarter of its 2024 financial year.

MC Mining, which is being bought out by Goldway Capital Investment, reports that the mine sold 75 590 t of high-grade coal during the quarter.

"The Uitkomst Colliery turnaround plan continues to yield very pleasing results, and RoM coal production significantly exceeded the comparative period in 2023. Production at the underground colliery remains challenging due to the geological conditions and extended travel time to the mining areas and unfortunately the mine recorded one lost-time injury during the quarter.

"The international and domestic thermal coal markets remain under pricing pressure and, during the period, the colliery continued to assess alternative marketing strategies, resulting in the signing of an offtake term sheet with Paladar [Resources] in April," MC Mining MD & CEO Godfrey Gomwe comments.

The coal miner reiterates that Goldway's takeover offer of A$0.16 a share was declared unconditional on April 8, and points out that, by April 29, Goldway held about 93.05% of MC Mining's shares.

It expects Goldway's takeover process to be completed on April 30.

Meanwhile, the takeover process adversely impacted on MC Mining's progress at the Makhado project during the March quarter.

This included the suspension of early works and early coal initiatives, as well as the managed tender processes for the selection and appointment of the outsourced mining, plant and laboratory operators at Makhado.

The takeover offer also resulted in the cessation of funding activities for the development of the project.

Activities are expected to be reinitiated once the takeover offer process is complete.

Further, at the Vele Colliery, measures to optimise operations are under consideration.

The mining and processing operations at Vele were outsourced to Hlalethembeni Outsource Services in late December 2022, but it experienced operational challenges in attaining the targeted monthly saleable coal production, while unit costs were adversely impacted by the lack of access to rail capacity to transport Vele's coal to port.

The challenges experienced by HOS were exacerbated by the decline in the API4 export thermal coal price during the 2023 calendar year.

As a result, HOS exercised the hardship clause in the outsource agreement during December 2023 and commenced downscaling operations at Vele. The downscaling was completed during January.

HOS subsequently initiated Operation Shandukani, a production optimisation strategy. The evaluation of these measures is expected to take place in the fourth quarter of the 2024 financial year and is expected to result in improved profitability at the colliery.

G7 nations to agree on first half of 2030s for phase-out

Group of Seven nations have agreed to target the first half of 2030s to phase out coal, according to the UK's energy and nuclear minister, a key milestone for some of the world's most industrialised economies seeking to switch to more sustainable fuels.

"To have the G-7 nations come around the table and send that signal to the world, that we, the advanced economies of the world, are committing to phasing out coal by the early 2030s is quite incredible," Andrew Bowie told Class CNBC, calling the agreement "historic".

The nations — the US, UK, Germany, France, Canada, Japan and Italy — agreed on the date after talks were held under Italy's presidency. The target is expected to form part of the final communique, and was not yet officially confirmed by Italy.

The G-7 ministerial meeting held in Turin is a pivotal moment for nations looking to chart a sustainable path ahead for their energy needs after Russia's invasion of Ukraine upended supply and demand equilibria that had been in place for years.

Who will buy Anglo's Aussie coal?

Anglo American said it has had "strong interest" in its five Australian coal mines it plans to sell as part of major asset breakup. But who are the prospective buyers?

The mines soon to be up for grabs include Moranbah North, Capcoal, Dawson, Aquila and Grosvenor, all situated in prime Queensland coal territory.

Around 5000 workers are employed across the mines, and Anglo emphasised these employees would be taken care of amidst the restructure.

"Of course, we are conscious of the impacts of making such far-reaching changes, particularly on our employees," Anglo chief executive officer Duncan Wanblad said.

"By implementing these portfolio changes ourselves, we will be able to do so in a manner that is respectful of our employees."

Queensland Minister for Resources and Critical Minerals Scott Stewart reaffirmed Anglo's commitment, saying he remained hopeful about the "strong future for steelmaking coal" and industry confidence.

Stanmore Resources, Whitehaven Coal, Coronado Global Resources, Peabody Energy, Teck Resources, and Glencore could also join the pot of potential suitors, given their respective synergies.

Top Glencore shareholders favour keeping coal over spinoff

Several of Glencore's largest shareholders believe that the company should retain its coal assets, according to people familiar with the matter, throwing a proposed spinoff into doubt.

Glencore, the world's largest shipper of thermal coal with a market capitalization of about $73-billion, had said it intended to spin the business off within two years of closing a deal to buy the steelmaking coal assets of Teck Resources.

But major Glencore shareholders believe that the company would be better off retaining its coal business, the people said, asking not to be identified because the information is private. The company's largest shareholders are former CEO Ivan Glasenberg, the Qatar Investment Authority, and BlackRock.

Glencore's coal business is one of its most profitable units, driving record returns in recent years, and the plan to exit coal and list a new company in New York represented a major strategic pivot under current boss Gary Nagle. The company had long resisted pressure to follow rivals in exiting the business, arguing that the world still needed the dirtiest fuel and that it was more responsible to run the mines itself than sell them.

It's not clear when and in what form Glencore might put the spinoff to a shareholder vote, with the deal to buy Teck's coal business yet to close. The shareholders will only form a final view once there is a concrete proposal on the table, and their stance could still evolve, the people cautioned.

While Glencore announced its intention to spin off its coal assets when it agreed to the Teck deal in November, it has since then made clear that the separation would only go ahead if shareholders wanted it.

A Glencore spokesperson referred to comments made by CEO Nagle in February.

"When we announced the transaction, we said our intention was to spin out, and that is our intention," Nagle told investors. "But it's always subject to what our shareholders want, and we will consult with our shareholders, and it's the decision of the shareholders ultimately to do that."

Glencore's coal business has long been a source of controversy among climate activists and some investors. In 2020, Norway's sovereign wealth fund said it had sold its Glencore stake due to the company's exposure to thermal coal.

When he unveiled the deal to buy Teck's coal assets in November, Nagle argued that a spinoff made sense because Glencore's coal and metals businesses would attract higher valuations as separate businesses than as one.

After the spinoff, Glencore's remaining business would be one of the biggest miners and traders of copper, nickel and cobalt, all essential commodities for the energy transition.

But Glencore's largest shareholders increasingly view the coal business as a cash cow that strengthens the entire company, the people said, and they see few benefits in spinning it off.

Glasenberg, the company's largest shareholder according to data compiled by Bloomberg, rose to become Glencore CEO after running the company's coal business and has long been a fan of the commodity.

Other shareholders like QIA also appreciate the cash flows that coal brings. Some, including BlackRock, might be forced to sell the coal business if it was spun off due to their own policies preventing them from owning coal-focused companies.

No one injured in Rio train derailment

There have been no injuries recorded after an autonomous train derailed at Rio Tinto's iron ore operations in the Pilbara region of Western Australia.

The incident reportedly took place after midnight on May 13 and saw the autonomous train hit a series of stationary wagons about 80km outside Karratha, impacting 22 wagons and three locomotives.

The train was said to have been loaded with an unknown volume of iron ore and was on its way to a nearby port when it collided into the stationary wagons and derailed.

"There were no people within the vicinity of the incident and no injuries," a Rio Tinto spokesperson said. "We have notified the appropriate regulators and commenced an investigation. Work will soon begin to clear the rail line."

The Office of National Rail Safety Regulator (ONRSR) has been notified of the incident and is carrying out an investigation.

"The recovery train is reported to have collided with the ore train it was sent to recover, after it was disabled by a mechanical failure," an ONRSR spokesman said.

"ONRSR is investigating the incident and will be making a series of enquiries, at this stage these are focused on the operation of and adherence to signalling systems in the area."

This is the second Rio Tinto autonomous train derailment in the Pilbara this year, with the first occurring in February. Another derailment also took place in June 2023.

None of these derailments have resulted in human injury or have been linked to the autonomous nature of the trains, which speaks to the strong benefits of autonomous machinery in creating a safer mining environment.

According to the Western Australian Department of Mines, Industry Regulation and Safety, the most common occurrence of injury on a mine site in 2022 was due to vehicle rollovers or falls from getting on or off a vehicle. By removing operators from vehicles and employing autonomous machinery, it seems fewer incidents will take place.

Rio Tinto operates approximately 50 driverless trains across the Pilbara and has been doing so since 2019, using the autonomous system AutoHaul.

China takes advantage of cheap gas and coal

China is taking advantage of lower international prices for coal and natural gas to replenish stockpiles of power fuels ahead of another long, hot summer.

Gas imports through the end of April jumped 21% from the previous year, while coal purchases climbed 13%. The increase in coal has defied predictions that imports would moderate from last year's record-setting pace and comes after domestic production posted its first quarterly drop since the third quarter of 2020.

Coal miners are wrestling with heightened scrutiny on safety after a spate of fatal accidents, as well as depleting quality after the rush to expand capacity in recent years. Producers of China's mainstay fuel is also putting limits on output growth as Beijing's deadline to peak coal consumption by 2025 approaches.

That is forcing utilities to lean more heavily on imports, an advantage given relatively lower fuel costs on the global market. The Japan-Korea marker for liquefied natural gas, Asia's benchmark, averaged just over $9 per million British thermal units in the first quarter, down from $18 in the same period in 2023. Newcastle coal futures in major exporter Australia averaged $127 a ton, from $236 in the prior year.

Ensuring power supplies has been a priority for policymakers since a series of embarrassing shortages in 2021 and 2022 forced widespread factory shutdowns. Meanwhile, another unusually hot summer in the northern hemisphere is forecast, which is likely to raise demand for air conditioning in coming months.

Even as China has dramatically ramped up wind and solar in recent years, its power demand, including from electric vehicles, continues to outpace new supply, creating an ever-greater need for fossil fuels. This year China's power consumption is expected to increase 8% in the first half, with peak demand expected to surpass last year's record by one hundred gigawatts — the equivalent of adding Australia to the grid.

Still, there are signs the country may have reached a tipping point where new clean energy installations are enough to meet additional usage, which will push fossil fuels and their emissions into a long-term decline. Gas and coal prices have also inched up in recent weeks, leading some gas buyers to offer to resell summer cargoes, suggesting that the surge in imports may cool. President Joe Biden will double, triple and quadruple tariffs on some Chinese goods this week, unveiling the measures at a White House event framed as a defence of American workers. Tariffs on China's "new-trio" exports would have a modest immediate impact on China's GDP and US-China trade, according to Bloomberg Economics.

The prime minister of Niger said neighbouring Benin had violated trade agreements between the two nations and Niger's Chinese partner by blocking crude shipments from Benin.

China's credit in April shrank for the first time as government bond sales slowed, while loan expansion was worse than expected in a sign of weak demand.

Indonesian authorities have arrested a Chinese national suspected of conducting illegal mining activities in Borneo.

Federal regulators look to block Montana mining law

The federal Office of Surface Mining Reclamation and Enforcement has indicated it will reject a law the 2023 Montana Legislature passed to loosen water quality laws that govern coal mining.

In a recent letter, Jeffrey W. Fleischman with the agency's Casper area office, flagged components of House Bill 576 as "inconsistent with" and "less effective than" federal laws such as the Surface Mining Control and Reclamation Act. Because federal law prevents states from adopting mining regulations that are weaker than federal standards, that assessment is likely to nullify the new state law.

HB 576, sought to amend the legal definition of "material damage" to water resources so it includes only "long-term or permanent" effects.

Since federal laws have no such temporal guidelines, HB 576 would limit the Montana Department of Environmental Quality's ability to initiate enforcement actions and order remediations for short-term, high-pollution events, Fleischman wrote. OSMRE also said that "long-term or permanent" is a "vague and difficult to enforce" standard that is not defined in Montana laws or rules.

The letter gave the state DEQ two options: share proposed policy changes to address the federal agency's concerns within 30 days or leave the new law unimplemented.

Montana lawmakers double down on fossil fuels in 2023 legislative session
How the recent legislative session passed a slew of laws that highlight lawmakers' energy priorities, and took direct aim at the pivotal case, Held v. Montana. by Amanda Eggert06.05.2023

OSMRE issued the letter about five months after it hosted a hearing in Billings to take public comment on HB 576 and Senate Bill 392, another measure state lawmakers passed last year. SB 392 seeks to require an individual or organization that sues to overturn a coal-mining permit to cover the legal fees incurred by

the other party if they are unsuccessful in their legal challenge.

Most commenters at that Nov. 8 hearing opposed the new laws, arguing that coal mining already threatens their access to high-quality water and saying they've seen sub-standard enforcement or remediation when violations are reported under the existing framework.

DEQ spokesperson Moira Davin wrote in an email to MTFP on April 19 that the department has not received a letter from its federal counterpart on SB 392, which has been incorporated into the latest version of Montana Code

Cokal ramps up BBM project works

BBM Mining has mobilised three additional mining fleets at Cokal's Bumi Barito Mineral (BBM) metallurgical coal project in Indonesia.

Cokal said the equipment is already arriving at Karjan, Indonesia, with BBM Mining set to complete the commissioning and initial setup of the new fleets once they arrive.

The five full fleets will begin operation at the beginning of June.

"Now that we are proving the logistics chain with a number of recent successful coal deliveries to Taboneo, Cokal is in a position to start ramping up production to meet demand from initially local customers but also, in due course, international demand," Cokal chief executive officer Karan Bangur said.

"Currently, we can sell all of our production to existing customers and are seeking to expand production to fulfill their demand as well as commence supply to new customers."

Cokal is also finalising construction of additional camp facilities at the Pit 3 area of the BBM project in order to accommodate an additional 125 personnel to operate the fleets.

In January, Cokal announced that the construction of the Batu Tuhup permanent jetty is tracking well, with the weighbridge works 70% complete at the time.

The company has now revealed the Batu Tuhup weigh bridge is complete and several road upgrade works within the Batu Tuhup jetty area are progressing to improve the movement of increased volumes of coal production.

Cokal is also undertaking ongoing screening of Seam J coking coal product so its current ash levels are managed.

Cokal owns 60% of the BBM project and the Indonesian Government owns the remaining 40%.

Wyoming coal producers plead for state tax breaks amid new federal rules, crushing market forces

Lawmakers granted a coal severance tax break in 2022, and will consider lowering it again.

With the state's coal industry facing increasing federal regulations and a declining market, lawmakers are considering whether state subsidies, in the form of tax breaks, might mitigate the financial turmoil destabilizing a $650 million pillar of Wyoming's economy.

The Legislature's Minerals, Business and Economic Development Committee last week agreed to consider a pair of tax break ideas brought by the Wyoming Mining Association in hopes that reducing state revenue might pay dividends in maintaining coal production and thousands of jobs in the state that otherwise might disappear.

"These are tough times," Wyoming Mining Association Executive Director Travis Deti told the committee. "Not only for the coal industry, but for the mining industry in general."

Deti suggested lawmakers reduce the state's severance tax rate for coal from 6.5% to 6% – a tax break that could save the industry tens of millions of dollars annually.

The coal association also suggested a tax credit strategy to benefit not only coal, but all mining operations, including trona and uranium. The idea is to discount mines' state severance tax bills based on a percentage of local sales taxes paid when purchasing new mining equipment – an incentive to invest in continuing mining operations in the state, Deti said. He suggested crediting coal operators for 35% to 50% of sales taxes, and limiting the incentive to mining equipment used at existing mining operations in the state.

"It just kind of gives the company a little incentive to keep investing in their Wyoming operations and gives them a little bit of tax relief when they have to make those investments," Deti told committee members.

But the goal of maintaining or even boosting natural resource production by lowering state taxes and fees has long been in question in Wyoming.

The Mineral Tax Incentives, Mineral Production and the Wyoming Economy study, often referred to as the "Gerking report" for the study's lead author, Shelby Gerking, concluded in 2000 that various state severance tax reductions do not have a significant impact on employment and production.

"We've seen study after study to this effect," said Shannon Anderson, attorney for the Sheridan-based landowner advocacy group Powder River Basin Resource Council. "State tax policy does not drive whether or not minerals get produced. It's geology and commodity prices. It's the global economic picture. The whole basis of a severance tax is that this is a one-time opportunity to tax this finite mineral resource."

Coal's outlook

Wyoming has heavily relied on coal mining for the past 50 years, dedicating much of the revenue to funding K-12 schools and growing the state's Permanent Mineral Trust Fund. So when there's a decline in coal production, there's a corresponding impact on the state's budget.

And coal's current outlook spells trouble for the state's finances.

Wyoming coal production has decreased by nearly half since 2008. (University of Wyoming)

Wyoming coal exports to the U.S. utility market were down 20% during the first quarter of the year due to a mild winter, low natural gas prices and increasing competition from renewable sources of electric power generation. On-site stockpiles of coal at power plants remain flush, according to the U.S. Energy Information Administration, which means demand for Wyoming coal is likely to remain lower than usual in coming months.

Adding to the industry's troubles, the U.S. Environmental Protection Agency recently issued four new rules to drastically reduce coal pollution, including a 2032 deadline for coal-burning power plants to cut planet-warming carbon dioxide emissions by 90%, or convert to natural gas or close altogether. That means Wyoming coal's market – which almost entirely consists of U.S. power plants – is likely to shrink even further.

Though Wyoming has already joined several other coal-reliant states in a pair of lawsuits to block the new federal rules, utilities are under pressure to convert or close coal plants under the assumption that the rules might stand, according to one coal industry attorney.

"Things are difficult," Deti said. "Market conditions are tough."

Lingering doubts

Industry officials representing Wyoming coal, oil and natural gas frequently

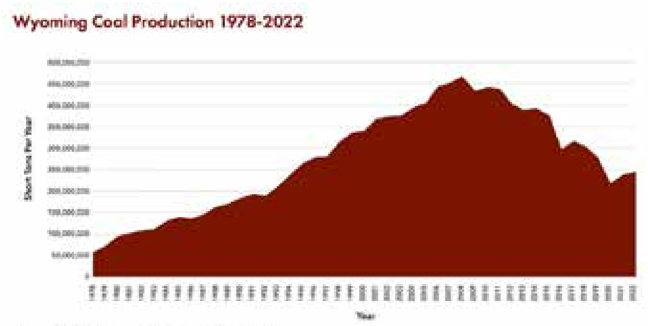


Figure 1: Wyoming Coal Production 1978-2022

propose tax breaks and other state-level financial incentives, insisting that decreasing direct revenue is outweighed by maintaining jobs while keeping the core of Wyoming's mineral-derived economic revenue in place.

In fact, that argument prevailed in 2022, when the Legislature lowered the state severance tax rate for coal from 7% to 6.5% – about a $10 million annual savings for coal operators in the state. Whether the tax break has effectively maintained coal mining jobs and kept some mines in operation that might have otherwise closed is an open question.

Before the severance tax break was enacted, Arch Resources – the state's second-largest coal producer – had already announced its intention to eventually close its two Wyoming mines without setting a timeline. Although the Black Thunder and Coal Creek mines are still in operation, Arch said it plans to eventually close them. The company recently hinted at layoffs due to a continually declining market for Wyoming coal.

"State tax policy does not drive whether or not minerals get produced. It's geology and commodity prices. It's the global economic picture. The whole basis of a severance tax is that this is a one-time opportunity to tax this finite mineral resource."
Shannon Anderson, Powder River Basin Resource Council

During the committee's discussion, Rep. Cyrus Western (R-Sheridan) questioned the merit of another severance tax break and asked Deti what coal companies are doing with the savings.

"Trying to stay alive," Deti responded. "This body, and the industry, we've got to strike the right balance to where we are in the market and in the current state of affairs."

The committee withheld action on the proposals, noting that the Revenue Committee might take up the issue when it meets later this month in Casper.

Anderson, of the Powder River Basin Resource Council, told WyoFile there will likely be significant opposition to a tax break for the industry.

"We have an obligation, not only to this generation, but future generations, and to make sure that we get adequate revenue for that resource because, once [coal] is mined, it's gone forever."

Dustin Bleizeffer

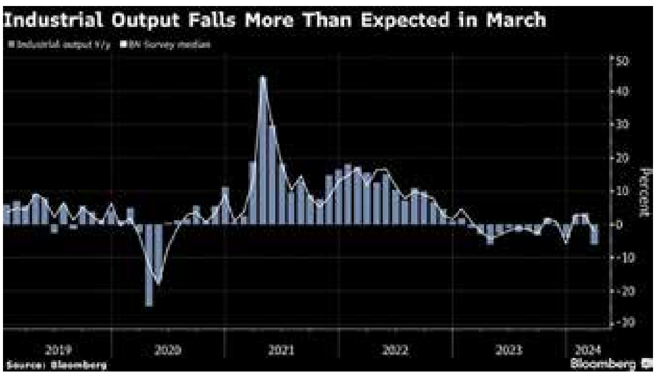
Poland's output drop raises questions over economic revival

Poland's industrial output fell most since April 2023 due in part to lower coal production, reducing the outlook for economic growth.

Industrial output in the European Union's most coal-reliant nation fell by 6% in March from the same month a year ago, while economists surveyed by Bloomberg saw it shrinking by 2.2%. Coal mining dropped 25.9% while electrical appliance production declined 29.1% from a year earlier.

Bank Pekao SA analysts, led by Ernest Pytlarczyk, said the data amounted to a "massive drop" in industrial output. Monika Kurtek, chief economist at Bank Pocztowy SA, said it was now "unrealistic" for Poland's first-quarter gross domestic product to expand by 2% or more — adding that growth is now seen at 1% to 1.5% year-on-year.

Bank Millennium SA economists, led by Grzegorz Maliszewski, see the fall in output as a "short-term disruption," unlikely to change the outlook for monetary policy. While his 2.3% forecast for first quarter GDP growth is likely to be missed, revival remains the "base case scenario" over future quarters, he said.



"Due to high core inflation, as well as high wage growth, the MPC will keep interest rates unchanged in the coming months," Maliszewski said.

Poland produced 64% of its electricity by burning coal in the first quarter, down from 68% last year. Meanwhile, solar energy output jumped 40% in March, compared with a year earlier, limiting demand for the dirty fuel, according to data from the country's power grid. The latest detailed data for February show the country's coal stocks more than doubled compared with the same period of last year.

South Africa's ANC walks political tightrope over coal plant shutdowns

In a ward South Africa's governing African National Congress (ANC) won handily in local elections three years ago, party campaign worker Poppy Vilakazi has been getting a decidedly frosty reception lately.

"Mostly they are angry," she told Reuters, speaking in Komati, a village in the shadow of a shuttered power plant in Mpumalanga province, an ANC stronghold in the country's coal belt.

"They feel the ANC let them down by allowing this power station to close."

South Africa's creaky power sector and the economic fallout from state utility Eskom's struggle to keep the lights on are top issues in a May 29 election that polls predict could see the ANC lose its 30-year parliamentary majority.

But as President Cyril Ramaphosa seeks to balance the need to boost energy output against dwindling funding for coal - which generates 80% of the country's power - and global demands that South Africa decarbonise, the issue is dividing his party.

Nowhere is that more evident than in Komati, where the conversion of a 60-year-old, 1,000-megawatt coal power plant has triggered a local and national backlash.

Eskom is installing 370 megawatts of solar, wind and battery storage at Komati. It is meant to be a blueprint for future coal station closures and create new jobs and training programmes in the renewable energy sector.

But local residents like Dumisani Mpungose - laid off from his maintenance job at the plant - say so far, they've seen nothing but unemployment, poverty and rising crime.

"Komati was a place of happiness, of life," said Mpungose, 37, whose wife returned to her parents' home after he lost his job, taking their daughter with her. "It's been two years I haven't seen them now. Two years that I haven't been working."

Ramaphosa's ministers have piled on the criticism.

Mineral Resources and Energy Minister Gwede Mantashe labelled Komati's closure a disaster. Electricity Minister Kgosientsho Ramokgopa called it a mistake and has successfully lobbied cabinet to delay future closures.

"If you can't make your pilot work, it's going to send a very bad message. It means you've failed," said Chris Yelland, an energy expert who believes South Africa must pivot to renewables but worries Komati risks undermining that shift.

The ANC's main rivals - and potential coalition partners if it loses its majority - are proposing their own solutions.

The left-wing Economic Freedom Fighters want to stop decommissioning coal plants and add new nuclear capacity, while the centre-right Democratic Alliance wants to liberalise the sector and break Eskom's monopoly.

Hefty bill

Years of mismanagement, corruption, and neglect crippled Eskom. Near daily blackouts have curbed economic growth and contributed to one of the world's highest unemployment rates.

Eskom is pushing its ageing fleet to the limit. But that's undermining commitments South Africa, the world's 14th biggest producer of carbon emissions from energy production, made under the Paris climate agreement.

South Africa's global partners are not the only ones concerned. A youth survey released this month by the Johannesburg-based Ichikowitz Family Foundation, which backs wildlife conservation and youth empowerment projects, found that 63% of South African respondents were "very concerned" by climate change, a 26-point jump in just two years.

However, funding a shift away from coal could cost up to $46 billion.

That is too hefty a bill for the government, so it's turning to the United States and wealthy European countries, who have pledged an initial $8.5 billion in financing, most of it loans.

South Africa has committed to cutting emissions to between 350 and 420 million metric tons annually by 2030, from 442 million tons this decade.

"We will prove that this can work," Thevan Pillay, Komati's managing director, told Reuters. "We'll do that in the rest of the fleet. And it will change the mindset of people."

Residents in Mpumalanga, which produces the bulk of South Africa's power and is the heart of a coal industry employing over 90,000 people, are sceptical.

"What are we going to eat if all the coal mines are closed, and all the power stations are closed?" said Anna-Marth Ott, who heads the chamber of commerce in Middelburg, one of Mpumalanga's commercial hubs.

"How are we going to sustain the economy?"

With thousands of unionised miners and Eskom workers, Mpumalanga is a bastion of organised labour, the bedrock of ANC support. Black coal entrepreneurs are key ANC financial backers.

Neither group is happy.

Despite the internal dissention, few doubt the ANC will carry Mpumalanga at the polls.

But in an election where it needs every vote it can get, many like Dumisani Mpungose do not see the point in turning up for a party they feel has betrayed them.

"This seems like a sell-out," he said of the Komati plant closure.

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Getting serious about decarbonisation

Mining companies need to address decarbonization and meet their ESG commitments. Most need tools to improve their data on emissions throughout their supply chain and should work to benefit the communities in which they operate.

Amid growing demands to reduce their climate impacts, mining companies have begun to explore how to move beyond risk identification and mitigation to execute on their decarbonization agendas. This is a critical area as companies work to meet the environmental mandates associated with their environmental, social, and governance (ESG) commitments as well as win back the trust of investors. Here we outline several practices miners can use to think through the context in which decarbonization might make sense for their organizations so that they can clearly visualize their risks, optimize their strategies, and realize their opportunities.

Driven by external pressure to reduce greenhouse gas emissions and a strengthening business case for diesel replacement and electrification, many mining companies have been making strides toward decarbonization. In Chile, for instance, BHP, Anglo American, and Antofagasta Minerals have all announced plans to power local operations from entirely renewable resources.[1] For its part, Vale has committed to achieving 100% self-production from renewable sources by 2025 in Brazil, and by 2030 globally.

With renewable energy approaching price parity (at least for some renewables), the cost of taking action is also decreasing. While the costs of transitioning must also be considered, operationally it is now much cheaper to replace fossil fuels with renewables and, in many cases, attain significant economic benefits.

However, eliminating outputs, or even transitioning to a lower carbon footprint, is easier said than done. With each passing year, pension funds, institutional investors, and the ESG investment community demand more specifics about how companies plan to move from strategy to execution.

DEMANDS FOR ACTION MOUNT.

Providing these specifics has become paramount amid a mounting demand for action. Beyond conducting climate-related stress testing, some banks are divesting holdings or refusing to invest further in companies that fail to meet their ESG commitments.

Asset manager BlackRock announced its divestment of certain thermal coal securities from its discretionary active investment portfolios in early 2020, stating in a letter to its clients: “With the acceleration of the global energy transition, we do not believe that the long-term economic or investment rationale justifies continued investment in this sector.” Members of the Net-Zero Asset Owner Alliance, representing US$4 trillion in assets under management, have committed to transitioning their investment portfolios to net-zero emissions by 2050.[5] Already, we have seen several pension funds advising their portfolio companies to adopt net-zero plans as a condition of remaining on the share registry.

"Mining companies should recognize that there is a correlation between stakeholder sentiment and company valuation," says Henry Stoch, partner, Risk Advisory and National Sustainability and Climate Change leader, Deloitte Canada. "Companies that fail to commit to a decarbonization agenda could find their share prices affected, which strengthens the case for decarbonization."

Governments are getting into the act as well. In Canada, for instance, companies that could not demonstrate adherence to their obligations under the Taskforce on Climate-related Financial Disclosures (TCFD) were not eligible to receive COVID-19 relief funds.

Considering these realities, many companies are adopting a range of leading practices as they move from decarbonization commitments to action, balancing short-term economic factors with long-term environmental impact. While some of the approaches explored here are still nascent, they represent a set of practices adopted by many firms in the industry and in adjacent sectors. These should help enable miners to think through the context in which decarbonization might work for their organizations.

PRACTICE 1: STAKEHOLDER RESPONSE SCENARIOS

The mining industry is familiar with the potential for community grievances to spill over into unrest, and that's particularly true for matters related to ESG. As a result, many industry players are already preparing for potential litigation. In an increasingly divisive geopolitical environment, the risk of climate terrorism is also on the rise, opening the door to attacks, both physical and cyber.

Conversely, as companies consider abatement options, they can design in benefits for the communities in which they operate to lower emissions and build community support. For example, as companies establish carbon trading and offsetting strategies, including local nature-based solutions with the ecosystem and other local benefits, they could deliver good outcomes for all stakeholders.

To understand how different stakeholder groups might react if companies continue contributing to climate change or, alternatively, lower their emissions to deliver community benefits, Deloitte modelled various possible scenarios, ranging from moderate to extreme, over a 10-year timeline. For instance, could employees refuse to work for a company due to its weak environmental record? Could a company be sued for billions of dollars for contributing to climate change? How are core investor groups likely to react?

This is just one element in the effort to gain a comprehensive understanding of what the future of energy means from an organizational perspective. As companies attempt to execute against their decarbonization agendas, they should assess a wider range of physical and transition risks, taking regulatory, market, and stakeholder considerations into account to determine the climate risks that may affect all their operations.

Although there are various steps along this path, the process typically begins by aggregating current emissions data, creating realistic forecasts, and examining various abatement scenarios to pinpoint those that can enable companies to achieve their emissions targets and build strategic competitive advantage (see case study).

CASE STUDY: MOVING TO NET-ZERO.

After committing to a net-zero target in line with the 2015 Paris Agreement, a global resources company needed to evaluate a range of abatement pathway options to identify the costs associated with achieving this target. Through a series of in-person and remote workshops, the project team:

- Analysed the company's current and forecasted emissions data.
- Helped identify, quantify, and articulate potential abatement pathways for achieving and maintaining net-zero operations.
- Modelled the potential value, costs, timing, and technologies associated with various abatement solutions and how they interacted with the forecast demand for lower carbon commodities.
- Developed robust options for interim targets.
- Reviewed carbon offset pricing forecasts, which allowed the company to assess its medium- to long-term decarbonization options.
- Assessed and reported on emissions impacts, abatement partnerships, and procurement options.
- Analysed how the company's valuation might be affected by potential stakeholder reactions and estimated the cost of those capital impacts over the next decade.
- Explored options to integrate emissions data into the company's enterprise resource planning (ERP) system to enable fully informed decision-making.

This work generated a collection of papers that provided the executive team and board with guidance on global strategy, laying out the activities the company should consider as they transition to a low-carbon economy. As a result, an internal fund was established to help accelerate the deployment of abatement projects.

PRACTICE 2: DEEP-DIVE EMISSIONS PLANS

Although an important first step on the decarbonization journey involves setting a global plan and priorities, companies cannot achieve their objectives unless they understand the specific actions, they're required to take at the site level. This speaks to the need to develop deep-dive emissions plans for specific assets and mine sites. Among the various considerations, three components to focus on include:

- **Site power.** As companies tackle the logistics involved in accessing electricity as and when it's required, they should consider a range of options. In some cases, for instance, it will make sense to enter power purchase agreements (PPAs) to acquire power through the grid. In other cases, they may choose to underwrite renewable development. Understanding the pros and cons of each course of action can be essential before proceeding. In a recent example, BHP entered new renewable energy contracts for its Escondida and Spence copper mines in Chile that allowed the company to reduce energy prices by 20% and displace 3 million tons of CO2 emissions from the current coal-fired supply. The company also signed a renewable PPA that will allow it to use low-emission energy sources to meet half of its electricity needs in its Australian, Queensland coal mine, a move that should see the company reduce its related emissions by 50% by 2025.
- **Material movement electrification.** Once a company decides to replace diesel across its mining operations, it will need to think through alternative approaches, such as whether to transition to hydrogen or electric vehicles, what trolley-assist options exist, the availability of stationary power generation, and options for in-pit crushing and conveying. For Anglo American, this decision-making process saw the company partner with ENGIE to develop and fuel the world's largest hydrogen-

powered mine haul truck, which it expects to roll out at its Mogalakwena platinum mine in South Africa.

- **Processing.** When it comes to processing operations, machinery and vehicle electrification is only one element companies must consider. They should also implement any required process changes and seek to optimize their operational emissions through abatement projects, policy analysis, and portfolio assessment. This is an approach Rio Tinto is pursuing as part of its joint venture with Alcoa Corporation to eliminate carbon from the aluminium smelting process.

"Regardless of the choice they make, miners should undertake an in-depth review of how these activities might impact worker safety and productivity," says John O'Brien, partner, Financial Advisory, Deloitte Australia. "This, in turn, should be balanced against appropriate capital planning to develop the optimum project mix."

PRACTICE 3: ERP INTEGRATION

Given the compounding impacts of climate change across the enterprise, there is a growing need to seamlessly integrate emissions data with a company's operational and financial data. In addition to positioning companies to make more informed capital project decisions, access to real-time data is essential if miners hope to understand the trade-offs they must make between emissions reduction, financial resources, and productivity.

Many ERP providers are already taking steps to turn this vision into reality. In early 2020, SAP undertook an initiative to understand how SAP S/4HANA and other SAP applications could help companies manage their carbon footprints. This review led to the establishment of the Climate 21 program, which aims to help companies track product-related emissions data and optimize their carbon transactions across both their supply chains and asset base. In a similar move, Salesforce introduced the Salesforce Sustainability Cloud, which is designed to help users quantify their carbon footprint and take steps to reduce emissions by tracking, analysing, and reporting on their environmental data.

While it is still in its early days, the integration of emissions data into ERP systems promises to drive more informed decision-making, shed light on the strategic impact of various climate-related programs, and enable real-time assessment of the trade-offs between emissions, productivity, and finance.

Given the compounding impacts of climate change across the enterprise, there is a growing need to seamlessly integrate emissions data with a company's operational and financial data.

PRACTICE 4: SCOPE 3 EMISSIONS

Greenhouse gas emissions are typically classified into three groups, or "scopes." Scope 1 emissions are those that companies emit directly from owned or controlled sources. Scope 2 emissions are indirectly emitted through the generation of purchased energy. Scope 3 emissions are indirectly emitted across a company's value chain.

Companies at the early stages of their decarbonization initiatives will typically focus on measures to reduce their scope 1 and scope 2 emissions. Now, however, companies are increasingly expected to work with their customers, suppliers, and other value chain partners to reduce their scope 3 emissions. Many organizations have begun to see the reduction of scope 1 and scope 2 emissions as the minimum and are making the reduction of scope 3 emissions their focus.

This appears to be reflected in growing industry participation in associations such as the:

- Australian Climate Leaders Coalition, a group of cross-sectoral Australian CEOs who are setting public decarbonization targets.
- Japan Climate Leaders' Partnership, a coalition of Japanese companies that believes economic prosperity and sustainability go together.
- New Zealand Climate Leaders Coalition, which is focused on helping the transition to a low emission economy.
- European Corporate Leaders Groups, which bring together business leaders committed to supporting the transformation to a net-zero economy; and
- We Mean Business coalition, which is driving US policy ambition to accelerate the zero-carbon transition.

Although each company must assess its strategic approach relative to scope 3 emissions, those choosing to play a part in addressing these emissions are now considering use cases that would allow them to aggregate emissions data and build partnerships across their extended value chains.

As an example, Rio Tinto and Baowu Steel signed a memorandum of understanding (MOU) to develop a hydrogen substitute to lower emissions across the steel supply chain. The hydrogen would be used as a reductant in the steelmaking process to replace coking coal—a move that could potentially address the challenge of scope 3 emissions.

PRACTICE 5: ENHANCING DISCLOSURES BY IMPROVING TRACEABILITY.

Although early demands for provenance were likely sparked by the need to eliminate conflict minerals from supply chains, social expectations around ethical sourcing have burgeoned. With each passing year, a growing number of automotive manufacturers, technology companies, and global retailers are paying rigorous attention to the origin of the metals and minerals they source and sell—putting mining companies under greater pressure not only to improve product traceability but also to disclose the carbon footprint associated with the minerals they process.

"Beyond helping companies validate the source of specific commodities across the supply chain, blockchain technology can track the end-to-end carbon footprint involved in producing any particular ton of ore," says John O'Brien. "This could be critical as mining companies aim to certify both the ethical sourcing and carbon neutrality of their products."

As companies move from strategy to execution on decarbonization, they have the opportunity to create more resilient organization. By developing a clear road map and plan of action to meet their commitments to the market, they not only de-risk their organizations; they also lay the foundation for winning back the trust of the investment community.

THE PATH TOWARD DECARBONIZATION

- Understand the impacts. Before they can effectively decarbonize, organizations should seek to understand the impacts of climate change on both societies and their operations. Predictive analytics can help. Using historical data, companies can assess their current baseline and set targets accordingly, with the aim of proactively recognizing likely emissions generated from assets over their life cycle. Armed with this information, it can become easier to harmonize decarbonization efforts in primary operations, re-examine asset portfolios to identify opportunities for carbon reduction, and determine which technologies to invest in.

- Consider multiple abatement pathway scenarios. By leveraging scientific information from leading bodies and methodologies—including the Intergovernmental Panel on Climate Change (IPCC), Representative Concentration Pathways (RCPs), the International Institute for Applied Systems Analysis (IIASA), Shared Socioeconomic Pathways (SSPs), and the Science-Based Target (SBT) methodologies – companies can begin to compare the forecast emissions reductions associated with their proposed abatement projects. This can position them to assess the viability of a range of decarbonization initiatives, such as low carbon transition strategies, including target setting (e.g., net-zero emissions trajectories, science-based targets, least cost pathways); renewable energy procurement advisory and support, including PPA strategy; and renewable technology and policy scenario analysis, forecasting, and budgeting (financial and carbon use).

- Optimize operations. As companies move from strategy to execution, they should make operational adjustments to support their decarbonization agendas. This includes identifying innovative new technology to help drive energy savings; improving their sustainability reporting, assurance, governance, and compliance; taking advantage of tax credits to drive cleaner technology; and collaborating with other energy, resources, and industrial companies to build out cross-sector solutions.

From strategy to execution

Henry Stoch
Canada

NEWS, PLANT AND EQUIPMENT

New Study: The Price Tag Of Phasing Out Coal

Coal phase-out is necessary to solve climate change, but can have negative impacts on workers and local communities dependent on coal for their livelihoods. Researchers at Chalmers University of Technology in Sweden and Central European University in Austria have studied government plans for coal phase-out around the world and discovered that more than half of such plans include monetary compensation to affected parties. This planned compensation globally amounts to USD 200 billion, but it excludes China and India, the two largest users of coal that currently do not have phase-out plans. The study shows that if China and India decide to phase out coal as fast as needed to reach the Paris climate targets and pay similar compensation, it would cost upwards of USD 2 trillion.

To slow global warming, coal use needs to end. Many governments, mostly in Europe, have begun to phase-out coal, but these policies can harm companies, risk unemployment, and lead to economic hardship for coal-dependent regions. In response, some countries have adopted what are known as 'just transition' strategies, where governments support negatively impacted companies, workers, and regions. Germany for example, has pledged over EUR 40 billion to support those affected by coal phase-out.

"Previously, coal phase out has often been blocked by the interests opposing it. Many countries have put money on the table through 'just transition' strategies which has made coal phase-out politically feasible," says Jessica Jewell, Associate Professor at Chalmers University of Technology, and one of the authors of the study.

The researchers have studied all countries with coal phase-out plans around the world and found that those with the most coal power production and with plans for rapid phase-out, have compensation policies in place.

In total, these 23 countries with 16% of the world's coal power plants have pledged about USD 209 billion in compensation. This may sound like a lot of money, but the researchers point out that it equates to roughly 6 gigatons of avoided CO_2 emissions and the cost of compensation for coal phase-out per tonne of avoided CO_2 emissions (USD 29-46 per tonne) is actually well below recent carbon prices in Europe (~USD 64-80 per tonne).

"So far these 'just transition' policies are consistent with, or lower

than, the carbon prices within the EU, which means they make sense in terms of climate change. But more funding is likely needed if we want to reach the Paris climate target," says Jewell.

This is because achieving the goals of the Paris climate agreement will not be possible without participation of the world's major coal consumers, China and India, which have more than half of the world's coal plants, but no phase-out plans currently in place. The study finds that, for China and India to adopt compensation policies similar to those already in place, the estimated compensation amount for both countries would be USD 2.4 trillion for the 2°C target and USD 3.2 trillion for the 1.5°C target.

"The estimated compensation for China and India is not only larger in absolute terms, but would also be more expensive compared to their economic capacities", says Lola Nacke, a doctoral student at Chalmers University of Technology, and one of the authors of the study.

A big question thus is where such large sums of money would come from. Today about half of all compensation is funded from international sources such as Just Energy Transition Partnerships* supporting coal phase-out in Vietnam, Indonesia and South Africa. International finance might also be needed to support future coal phase-out compensation in major coal consuming countries.

However, the researchers point out that the estimated amounts of compensation for China and India alone are comparable to the entire international climate finance pledged in Paris, and larger than current international development aid to these countries.

"Discussions about the cost of climate change mitigation often focus on investments in renewable energy technologies – but we also see it's essential to address social implications of fossil fuel decline to enable rapid transitions", says Lola Nacke.

Fact Box:

***Just Energy Transition Partnerships** — Just Energy Transition Partnerships (JETPs) are new multi-lateral structures for accelerating the phase-out of fossil fuels. These intergovernmental partnerships coordinate financial resources and technical assistance from countries in the Global North to a recipient country to help it in this regard. JETPs related to coal phase-out are currently in place for Vietnam, Indonesia and South Africa.

EU Just Transition Fund – The fund is the first pillar of the Just Transition Mechanism. The Commission provides support to Member States having identified the territories expected to be the most negatively impacted by the transition towards climate-neutrality. The Just Transition Fund supports the economic diversification and reconversion of the territories concerned.

Paris Climate Agreement – To tackle climate change and its negative impacts, world leaders at the UN Climate Change Conference (COP21) in Paris reached a breakthrough on 12 December 2015: the Paris Agreement. The Agreement sets long-term goals to guide all nations to:

- substantially reduce global greenhouse gas emissions to hold global temperature increase to well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change.
- provide financing to developing countries to mitigate climate change, strengthen resilience and enhance abilities to adapt to climate impacts.

Embracing emerging technologies

It took centuries for the mining industry to innovate, replacing torches with Davy lamps, fire with gunpowder and dynamite, and pit ponies with steam engines trundling in and out of the mine on rails.

Picks and shovels, meanwhile, were supplanted by mechanical drills with internal combustion engines, fuelled by petroleum or diesel.

While these machines certainly sped up the extraction process, they also belched out their own suffocating gases, filling the pit with a miasma of carcinogenic carbon and sulphur dioxide intermixed with whatever particulate matter was thrown up by the drill bit.

Not only are fossil fuels harmful to the lungs of the miners that venture down into the murky depths of the pit – they are also running out.

As a result, operators require vehicles and equipment that are considered as dependable as those fitted with internal combustion engines, that do not emit noxious gases into the warren of shafts and tunnels that constitute the modern underground pit, and whose fuel source is easily and infinitely replenishable.

The solution for operators has been battery-powered electric vehicles, which are not only much cleaner and, in many cases, more reliable than their petrol-driven equivalents, but also serve as an effective base for future experiments in equipment automation within the mining environment.

The shift from a fossil fuel powered mine to an all-electric mine will require more than just a shift in the technology required. It requires a mindset shift by the broader industry. The predisposition to continue with what is comfortable, simply replicating existing asset design processes, is no longer viable as we think about 2030 and beyond. This will challenge an industry that traditionally has little risk appetite when it comes to mine design. In a recent industry survey only 20% of mining businesses stated they would accept risk in asset design to increase financial return. An all-electric mine requires a refresh in thinking about design across the entire value chain, and many traditional mine design principles will need to be set aside.

So, if we want to capitalise on this shift and embrace emerging technologies, what do we need to consider in the mine design process?

EQUIPMENT

While there are battery electric vehicle solutions available today, technology is still evolving. In designing an all-electric mine, not only must the fleet size and composition be considered, so must the ability for equipment solutions to adapt. Optionality will become critical to embed in decision making processes for equipment, allowing companies to

adopt to the emergence of new technologies with minimum disruption. Battery swapping, for example, is currently used in some electric vehicles. While this may be the best fit for certain mine sites now, for many it is seen as inefficient as it is capital intensive, and operations are interrupted to make the swap. Embedding optionality in fleet selection provides the opportunity for process efficiencies to be capitalised on as breakthrough technologies emerge.

VENTILATION

Using battery electric vehicles generally results in a decrease in required air volumes, which likely means building smaller, and potentially fewer, ventilation shafts. An all-electric mine not only creates benefits for worker health and safety (an electric fleet will reduce heat emissions by up to 90% and eradicates diesel particulate matter) but may also result in significant cost and efficiency savings. Given that ventilation can use up to 50% of a mines electricity, the economic benefit of reduced ventilation operating costs could be significant. The ability to design mines with smaller ventilation infrastructure from the outset will also reduce capital costs.

Most mines use complex ventilation systems – that can cost anywhere from $20 million to $400 million to install, and often require millions more per year to maintain – to regulate diesel emissions levels underground, said UBC's Madiseh.

By contrast, electric equipment doesn't produce fumes, which means companies don't have to spend as much on expensive ventilation.

"Diesel particulate matter – DPMs – are a huge concern, and the main reason you have ventilation in a mine is to dilute the diesel emissions," Madiseh said.

For Rakochy, the difference in air quality between mines that use diesel equipment and those that have electrified is stark.

"This will be a bit crude, but you generally will get up and you'll blow your nose. When you blow your nose, your Kleenex will be full of black soot," Rakochy said.

"You know that stuff has definitely gone into your nose and into your lungs. With battery-electric vehicle equipment, there's absolutely zero of that."

Particulate matter from diesel engine exhaust is carcinogenic and long-term exposure to these fumes lead to an increased risk of lung cancer and possibly bladder cancer. A 2018 study found that 2.4% of cases of lung cancer in Canada are attributable to occupational diesel engine exhaust exposure, and underground mine workers were among the occupations with the highest risk.

This is one of the reasons why Unifor's Santos welcomes the change.

"From a worker standpoint we're happy with the move away from diesel, especially when you talk about some issues we've seen with diesel particulates," Santos said.

MINE LAYOUT AND INFRASTRUCTURE

In a recent report 54% of mining companies expected infrastructure to be the main challenge for transitioning mine sites to electric. This is not surprising when you consider the needs of battery electric vehicles. Charging type, location, size of charging bays, feasibility of onboard charging, shift scheduling and optimal material movement are critical considerations for all mining companies.

Mine layout of electrical infrastructure will be key to optimising efficiencies. The strategic placement of charging stations will be important, as the timing and location of charging impacts how much energy is required and where at any given time. Optimising material movement can also impact energy efficiencies. By designing a mine that optimises haulage routes, there is the potential to capture energy from regenerative braking. While other infrastructure, such as trolley assist systems, need to be fixed, it is possible to capitalise on the charging opportunities from the overhead power bar system.

PROCESSING DESIGN

Shifting to an all-electric mine requires a shift in thinking around processing design and efficiency. Where an all diesel mine can be planned around 24/7 processing, an all-electric mine needs to ideally accommodate fluctuations in renewable energy. To accommodate this shift, one of two changes must be implemented. Either processing remains 24/7 and is supplemented by renewables stored in a long duration energy storage solution, or processing design must fundamentally change, allowing flexibility to ramp up processing during the day when there is proliferation of solar or wind energy. Minimal processing would occur at night, resulting in the need to 'stockpile' during the day.

The mine design process will continue to evolve as new technologies are developed. It is critical however, that we question the rule book of traditional mine design and consider new approaches to accommodate the future needs of electrification. We should not underestimate the mindset shift required to meet this challenge.

"Electrification is going to be one of the biggest technology shifts we've seen in the mining industry," says Henrik Ager. As President of mining equipment manufacturer Sandvik Mining and Rock Solutions, part of the Sandvik engineering group, Ager has a better view of the mining industry than most. It's also why his company is spearheading this electric revolution.

For the past 70 years or so, mining has relied on diesel-powered machinery, which tends to be hot and noisy, while generating particulate emissions. But the future looks very different, says Ager.

Sandvik is developing a new generation of machinery and equipment that is powered by electricity. The technology is already beginning to offer a cleaner, cooler, and more efficient alternative to diesel-powered mining.

The machinery used in mining has significant knock-on impacts. For example, diesel-powered machinery tends to generate pollutants and heat. This requires significant ventilation to be built into any infrastructure. Then there is the noise from internal combustion engines.

"The more we can reduce the dust and the heat, the better," says Ager.

Electrified equipment offers a solution. For a start, electric machines do not emit tail-pipe pollutants. "And they generate about 87% less heat," says Elina Pyykkö, Vice President of Product Development and Product Management in Sandvik Mining and Rock Solutions' Underground Drilling Division. "Given that underground mines are already quite hot as they are sometimes as much as 1000 meters below ground, it is a huge benefit to remove the additional heat rendered from combustion engines," she says.

QUIET REVOLUTION

The machines are much quieter, too. "There are significant health and safety benefits for people working in mines," says Ager.

But perhaps the biggest incentive for mining companies will be the economics, which are rapidly changing (See Electric Economics below). "For the moment, the upfront costs to develop electric machinery are higher than those associated with diesel equipment", says Ager. "But electric engines are simpler than internal combustion engines and so are cheaper to maintain and run", he adds.

Energy for electrified equipment costs less than diesel fuel, and without the diesel particulate emissions, there is less need for ventilation and cooling, which is a significant cost. Once these savings are factored in, electric equipment comes out as the cheaper option. "There's a very strong business case already," says Ager.

Transforming an industry is not without its challenges. Battery-operated machines must be adapted for the harsh environments they will experience underground. "We're putting electric equipment into an environment that is hot and humid," says Ager. That's not an ideal combination for anything electric.

Engineers began by removing diesel engines and fuel tanks from existing machinery and replacing them with batteries, but the development is now taking a more holistic approach. "Today, the entire machine is built around batteries and electric motors, making a much more efficient machine," says Pyykkö. That allows engineers to rethink the entire machine.

For example, the batteries that power electric equipment generally need recharging more often than diesel engines need refuelling, and this takes time. To get around this, the team at Sandvik have developed machines with batteries that can be easily swapped. When one battery runs out, the machine simply drops it and picks up a fully charged one. The used battery is then recharged while the machine continues to operate.

Engineers and operators also must learn how to build, handle, maintain and repair new equipment. "They're used to changing filters and oil, and now they need to handle something completely different," says Ager. "It's a different capability to get used to."

ADVANCED BATTERIES

Progress is rapid and continual. "Batteries are rapidly evolving, and every year there are new advancements," says Pyykkö. "It is key that we constantly adapt to the latest technologies and stay at the edge of what is possible."

The switch to electric-powered equipment can also reduce the impact of mining on the environment. "The total amount of CO_2 emissions from mining are estimated to be roughly 1.5 to 2% of global CO_2 emissions," says Pyykkö. "Electric vehicles could have real impact on the world."

One reason is that electric-powered equipment does not need to be powered by fossil fuels. "Electrification reduces a mine's carbon footprint since the machinery can be run from renewable resources," says Ager. "This will be more feasible once electrified equipment becomes the norm," adds Pyykkö.

And the change has already begun. Today, electric mining equipment accounts for around one% of the market, says Pyykkö. But companies like Sandvik are seeing demand surge, particularly over the last couple of years. "We're now in a trial period," says Ager. As new, electrified equipment becomes more common, it will become clear that electric-powered machines are better, or as good as, traditional diesel-powered ones. "Electric equipment is exciting because we have an opportunity to change the environment both in the mine and globally," says Ager. "The mine of the future is fully electric."

ELECTRIC ECONOMIES

Electric-powered mining equipment is cleaner, cooler, and quieter than traditional diesel-powered machinery. But crucially it has the potential to save costs too.

Machines that run on batteries can be more powerful than their diesel-powered equivalents. And as batteries become more capable – their voltage has trebled over the last decade – the machines can be powerful still.

As a result, battery-powered machines today have around twice the horsepower of their diesel-powered counterparts. And battery-powered trucks carrying heavy loads can travel around 10% faster than those powered by diesel. "They are strong," says Henrik Ager, President of Sandvik Mining and Rock Solutions. "The torque with electric is just enormous."

That translates into improved productivity. For example, loading material more quickly, carrying greater loads and travelling faster.

It also means that smaller machines can carry loads normally reserved for much larger diesel machines. For every 40 tonnes of material a diesel-powered truck can carry, an electric-powered truck of the same size can carry 50 tonnes, for example.

And because electric machines are smaller, tunnels can be smaller too. So new mines built for electric equipment require less digging than those designed for bulkier diesel-powered machines. "Smaller tunnels mean we move less waste rock and save lots of energy and lots of money," says Ager.

New electric mining equipment is available.

"We are building on a long history of using electric loaders powered by a trailing cable, and now we are looking at production machines powered from batteries," says Mattias Selberg, project manager for strategic projects, technical and process development at LKAB.

"For transportation of personnel, we can ride the wave of the general automotive development, but when it comes to production machines, a close cooperation with manufacturers is required."

A good working relationship with suppliers is not the only thing operators must remember if they are to pursue electrification at their mining site. Everything from the capital cost of the equipment being considered down to the design of the site itself needs to be carefully weighed before making a final decision on how to pursue this monumental change in approach.

The benefits – lower energy costs, cleaner air, a smaller environmental impact – are clear enough. Implementing such an upgrade, however, is its own battle.

For LKAB, electrification is an essential step in allowing it to continue extracting iron ore at its two principal mines in northern Sweden, Kiruna and Malmberget.

Future mining efforts will force the operator to dig at greater depths than ever before – perhaps as deep as 2,000m – which, in turn, will require the kind of efficiencies in energy use and ventilation that can only be afforded by the use of electric vehicles.

As such, LKAB has been busy transforming its two underground mines into test beds for the latest electric vehicles and autonomous mining equipment.

COLLABORATIVE EFFORT

The Swedish operator has learned several lessons while collaborating with other mining equipment and autonomous technology companies. The first is that converting any underground facility to handle electric vehicles requires careful consideration of numerous factors – one being if, in certain circumstances, you need them at all.

"Whether you use conveyors, hoists, electrified trucks or other [technology] depends on the volumes and distances," explains Selberg. Careful planning, too, is essential in making sure operators reap the full benefits of transitioning away from fossil fuels. "When planning the mine and production process you have a possibility to create the right circumstances for an efficient electrification."

That means moving beyond simply thinking of electrification as a straightforward process of shopping for shiny new battery-driven equivalents of a mine's ageing petrol-driven vehicle fleet.

Rather, any successful transition from the internal combustion engine to its more sustainable cousins requires additional investment in everything from electric motors and generators to traction battery systems and supercapacitors for energy storage and recovery.

Not the perfect answer

Electrification can present many other site-specific challenges too, not least in deciding where to place battery charging stations.

Electric mining haulage vehicles are, after all, capable of operating twice as fast as their diesel counterparts, but they possess a more limited range. Batteries are also affected by temperature, as Newmont Porcupine found when it discovered that its electric battery units couldn't be stored in the cold.

Other problems experienced might include harmonics in electrical infrastructure, causing charger malfunction or battery fires, and issues with tethered operations of scoops and no compressed air lines – to name but two.

To overcome these challenges, Selberg recommends that project managers remain agile and respond quickly to problems with the roll out of electric vehicles. In short, they should be ready – and able – to learn from early failures.

"Visit sites with similar production processes and logistic circumstances and see how they have handled the challenge. Think long-term and [about] the big picture, what to strive for, and have that well-anchored in the company," adds Selberg.

"Then, you can identify goals and take on the pieces of the puzzle. Start test operations on a small scale and gather experience along the way."

This article summarizes "The Electric Mine" report, highlighting key insights and notable company developments driving the mining industry's transition to full electrification.

DECARBONIZATION COMMITMENTS DRIVING ELECTRIFICATION

Mining companies are charging full speed ahead with plans to electrify equipment and operations. This drive is fuelled by ambitious net-zero emissions targets and facilitated by maturing technologies.

Leading mining companies recognize the urgent need to reduce emissions, aligning with the global shift towards clean energy. The sector currently contributes approximately 1 % to total greenhouse gas emissions. Notably, diesel-powered mobile equipment is responsible for 40-50 % of these emissions, while non-renewable electrical sources, such as coal and natural gas, contribute 30-35 %.

Substantial economic incentives are also driving this shift, as ventilation alone accounts for 30-50 % of underground mine energy costs, highlighting the significant impact of reducing diesel-powered equipment.

Mining companies with lower sustainability scores face 20-25 % higher capital costs. This makes electrification a strategic investment in the long run, aligning with the industry's commitment to both environmental responsibility and economic viability.

As a result, in 2021, a consortium of 27 major mining companies, as part of the International Council on Mining and Metals, committed to reach net-zero Scope 1 and 2 emissions by 2050. This commitment reflects a collective effort within the industry to address and mitigate the environmental impact of mining activities.

Technological Developments Enabling Widespread Mining Electrification

ADVANCES IN BATTERY TECHNOLOGY

Recent advancements in battery capabilities and charging systems have facilitated the swift rise of electrification over the last five years.

Traditionally, trolley systems were the primary method for electrifying haul trucks. However, in the 1980s, the Kiruna Electric Truck system revolutionised the industry. Commercial battery-powered trucks entered the scene in 2013, and by 2017, several original equipment manufacturers (OEMs) offered electric trucks and loaders. The momentum in electrification accelerated around 2018, marked by Epiroc's second-generation battery fleet launch.

At the end of 2022, mine operators had already deployed approximately 352 trucks with battery or hybrid technologies.

"Battery development has exceeded expectations," explained Mehrzad Ashnagaran, ABB's global product line manager for electrification and composite plants. "If you had asked us five to ten years ago, we could not have imagined where we would be today."

LARGER HAULAGE ELECTRIFICATION SOLUTIONS

The primary challenge for larger battery-electric haul trucks lies in designing a battery with the necessary energy density that can fit within the limited onboard space of the vehicle. However, significant progress has been achieved in expanding battery capacity to meet haul trucks' intensive energy needs.

For example, Williams Advanced Engineering, now under the ownership of Fortescue Metals Group, recently revealed a prototype battery system tailored for use in a Liebherr 240-ton haul truck. Additionally, Caterpillar has recently reported positive testing results for its first battery-powered 793 mining truck, which has a mammoth 265-ton haulage rating.

These developments demonstrate that mine-duty scale electrification is nearing commercial reality.

FAST CHARGING CONNECTORS

Some experts point to ongoing enhancements in charging connector capabilities, which enable faster power transfer, as the most important breakthrough in accelerating adoption.

In 2021, ABB unveiled eMine, a comprehensive portfolio designed to seamlessly integrate battery-electric vehicles in mining. It includes charging products that prioritize energy efficiency and optimize overall performance for efficient operation.

The eMine portfolio incorporates fast off-board charging stations strategically placed across the mining area to support smaller haul trucks engaged in near-continuous operations with limited idle time.

Depending on the battery size (100-400 kWh for smaller haul trucks), charging times range from 6 to 24 minutes for 30 % to 90 % charge and 10 to 40 minutes for a full 0 % to 100 % charge.

REVIVAL OF TROLLEY-ASSIST SYSTEMS

Trolley-assist systems are experiencing a resurgence as an interim solution for mine operators seeking to cut emissions from existing diesel fleets. These systems use hybrid diesel-electric trucks with a pantograph drawing power from an overhead trolley line, eliminating the need for diesel usage by 90 % while connected. This reduces emissions and offers substantial fuel cost savings.

According to ABB, converting one truck cuts CO_2 emissions yearly, equivalent to the absorption of 46,000 trees, while trolley assist boosts loaded dump trucks on gradients, enhancing hauling efficiency.

ABB successfully implemented this system at Boliden's Aitik open-pit copper mine in Sweden, connecting four large diesel-haul trucks to a 700 m trolley line, and at Copper Mountain's flagship mine in British Columbia, Canada, linking seven diesel-electric haul trucks to a 1km-long trolley line.

In both instances, the trolley-assist system significantly reduced diesel consumption, leading to operator cost savings and a significant reduction in greenhouse gas emissions.

ABB is also pioneering combined trolley-battery solutions for larger electric mining trucks. This concept involves partial in-motion recharges from overhead trolley networks supplemented by onboard batteries.

ABB foresees this combined approach as "potentially being the better solution for larger trucks, while the smaller-sized trucks can operate as full battery-equipped vehicles with the off-board charging system."

AUTOMATING THE ELECTRIC MINE ECOSYSTEM

- Mining Electrification: Transforming Mines for a Sustainable Clean Energy Future
- Shell Builds a Winning Consortium to Accelerate the Electrification of Off-road Mining Vehicles
- Major Mining Technology Innovations in 2023

Automation is the linchpin in optimizing the electric mine ecosystem by connecting and streamlining operations for increased efficiency, safety, and sustainability. It enables the deployment of autonomous vehicles, smart grids with renewable energy integration, and sensor networks for real-time monitoring and predictive maintenance.

Data analytics and artificial intelligence enhance decision-making, while robust communication networks facilitate remote control and safety measures. Automated systems also contribute to efficient supply chain logistics, making the electric mine ecosystem a seamlessly integrated and highly productive network.

ABB has been at the forefront of advancements in mining automation and control systems, as evidenced by its recent integration of automation and digital solutions practices in Kazakhstan, resulting in a doubling of capacity.

ABB's automated system Ability™ System 800xA monitors over 6,000 assets, optimizing maintenance, while crushers operate unattended from a control room in Canada. In Germany, ABB facilitates fully automated bulk material terminals, and in Sweden, their trolley assist electric truck infrastructure includes digital cargo tracking.

The company's automated ventilation platforms at the Boliden Kankberg gold mine in Sweden yielded over 50 % energy savings through real-time airflow adjustments in deep underground mines, significantly enhancing working conditions.

ALTERNATIVE ZERO-EMISSION DRIVETRAINS

Although behind battery-electric technology, hydrogen technology is being trailed at certain mines, such as Anglo American's Mogalakwena platinum mine in South Africa, indicating a growing interest in alternative solutions within the mining industry.

Liebherr showcased its expertise in hydrogen engines at Bauma 2022, winning the innovation award in the climate protection category for its H966 hydrogen-powered excavator. Liebherr is now exploring the potential of these engines to run on ammonia, with testing in an internal combustion engine anticipated in the near future.

ELECTRIFICATION'S COSTS VERSUS BENEFITS

Mining technology experts advise that fully electrifying operations may not represent the optimal decarbonization solution or deliver favourable economics at every mine site. While suitable for new mines designed with electric

drive equipment in mind, retrofitting existing facilities poses considerable challenges regarding layout and infrastructure.

Customers exploring electrification options should balance expected emission reductions with infrastructure expenses. For instance, Epiroc recorded major performance gains from electrifying models–energy savings of 70 %, 25-30 % lower preventative maintenance costs, 10 % productivity boosts, and noise reduction.

A thorough analysis is therefore crucial to determine if electrification yields sufficient reductions in carbon emissions and operational costs, justifying the capital expenditure.

PARTIAL ELECTRIFICATION

Since rapidly transitioning from diesel to electric operations remains extremely challenging, ABB suggests a gradual integration approach. Beginning with a small initial fleet of battery trucks allows miners to lower emissions while gathering operational experience.

This approach allows for gradually scaling up electric haulage and infrastructure in manageable phases, aligning with technology improvements and budget availability.

"A phased approach enables mines to immediately lower carbon footprints with a limited up-front capital investment while advancing progressively as technology becomes more mature, scalable and cost-effective." Mehrzad Ashnagaran.

INDUSTRY COLLABORATION DRIVES STANDARDIZATION AND INTEROPERABILITY

The specialized demands of adapting battery and hydrogen solutions for intensive mining applications have galvanized increased collaboration between vehicle OEMs, charging/ power vendors, and end customers. Aligning technical standards and control interfaces for safety, efficiency, and fleet flexibility represents a key focus area.

One prominent example is the Global Mining Guidelines Group, which actively shares underground mining electrification best practices across industry stakeholders. In July 2022, the organization published extensive recommended practices spanning mine layouts, electric vehicle designs, battery technologies, charging methods, and performance metrics.

STANDARDIZED EQUIPMENT

Mining companies increasingly demand standardized charging infrastructure to enable flexibility across various OEMs. This allows mines to choose battery-powered haul trucks and loaders from different suppliers while ensuring compatibility with shared recharging systems.

For example, Glencore aims for its Ontario-based Onaping Depth nickel-copper underground mine to be one of the world's first fully electric mines. To achieve this, Epiroc will provide universal CCS Type-1 chargers, ensuring seamless integration of mixed-brand electric fleets with a priority on interoperability to avoid vendor lock-in.

However, enabling multi-OEM equipment interoperability requires adopting universal connector standards

Electric-powered Zambonis hit the ice to prevent.

for seamless integration with shared high-voltage infrastructure. ABB advocates collaboration between OEMs and technology providers such as Hitachi, Liebherr, and Komatsu to align their offerings with comprehensive site-wide electrification, automation, and digitization systems.

These collaborative approaches are instrumental in addressing the complexities of integrating diverse equipment seamlessly into a shared high-voltage infrastructure.

EMERGING NEW RISKS

Canadian mining companies are starting to cast aside the diesel-powered trucks, loaders, and drills that have long-been the backbone of the industry for electric alternatives – a move that some industry experts say could make mining safer and less polluting.

Mario Santos, mining director for Unifor, Canada's largest private sector trade union representing 9,900 mining and smelting workers, said he welcomes the shift. "I think it's a positive change. It's better than the processes we were using before," he said.

Management consulting firm McKinsey & Company estimates that the mining industry accounts for four-to-seven% of global greenhouse gas emissions, and industry members say electric mining equipment has the potential to lower these emissions while also reducing operating costs.

More importantly for workers who spend their days operating heavy-duty machinery deep beneath the earth's surface, this switch would clean up the diesel-filled air they breathe day-in and day-out.

But – as the union leader is quick to point out – this change also presents new operational challenges and safety risks. And although electric equipment has been slowly trickling into mines for over a decade, some say there's still work to be done to bring safety standards and training up to speed.

"Until we move to a point where we're able to eliminate those risks – which is a tough thing to do – there's always going to be a concern," Santos said.

ELECTRIFICATION IS THE ONLY SOLUTION.

Today, many important mining tasks can be accomplished with electric equipment. Electric drills are used to dig into rock, electric vehicles – like trucks and loaders – help move material around sites, and electric conveyor belts and pulley systems do the same.

North American mines started testing out heavy-duty electric equipment – mainly vehicles attached to electric trolley lines – in the 1990s. But, Canada was one of the first countries to introduce battery-powered electric vehicles to mining in 2012.

Most in the industry were hesitant to be the earliest adopters of the new and largely unproven technology, said Dale Rakochy with Sandvik Mining and Rock Solutions, a Swedish engineering company that produces electric and diesel-powered mining equipment.

"Nobody wants to really be the Guinea pigs with new technology because it does pose some challenges for operations," he said.

Ice resurfaces (aka Zambonis) typically run on diesel or propane and can spew potentially unsafe levels of nitrogen

British company upcycles old diesel trucks into electric.

oxides in ice rinks. Now, new technology is helping them go electric and clear the air.

Now, after nearly a decade of use, the technology is proving its worth and hesitancy is dissipating, said Rakochy. He's seeing more mines interested in going electric.

"We will have more mines coming on stream with battery-electric vehicle technology almost monthly now as we go through the years," he said, noting that Sandvik's battery-powered electric vehicles are currently going online in their fourth Canadian mine.

Epiroc, another major electric mining equipment manufacturer out of Sweden, has 16 vehicles operating in Canada and expects to nearly double this count over the next few years.

SAFETY CONCERNS

But Santos says part of the challenge is that risks – like electrical fires and vehicle collision hazards – differ between worksites. It can be difficult to spot these risks until the equipment is operating on location, he said.

Given the confined nature of mines, Santos says his main concern is battery fires, a worry shared by Tom Welton, the director of health and safety services and education programs at Workplace Safety North.

"It's not seen very often. If it does happen it can result in catastrophic effects," Welton said.

Welton's risk assessments found that fires usually resulted from damages to the battery itself, or through improper handling.

U.K.-based Lunaz Applied Technologies extends the working life of disused diesel-powered recycling trucks by converting them into fully electric-powered vehicles. The company says it can retain more than 80% of the original vehicle's embedded carbon and save money.

Sandvik's Rakochy agrees that fire is a risk with battery-powered mining equipment, but he says this is also the case with diesel equipment. He says mitigating this risk is a matter of proper education and management.

Workplace Safety North identified collisions as the most common risk associated with battery-electric vehicles, which are considerably quieter than those with diesel combustion engines. While that means less strain on the hearing of workers, it also means there's an increased risk of mining vehicles going undetected.

"Battery-electric vehicles can be very quiet and can move very quickly throughout a mining operation and potentially put pedestrians in hazard's way," Welton said.

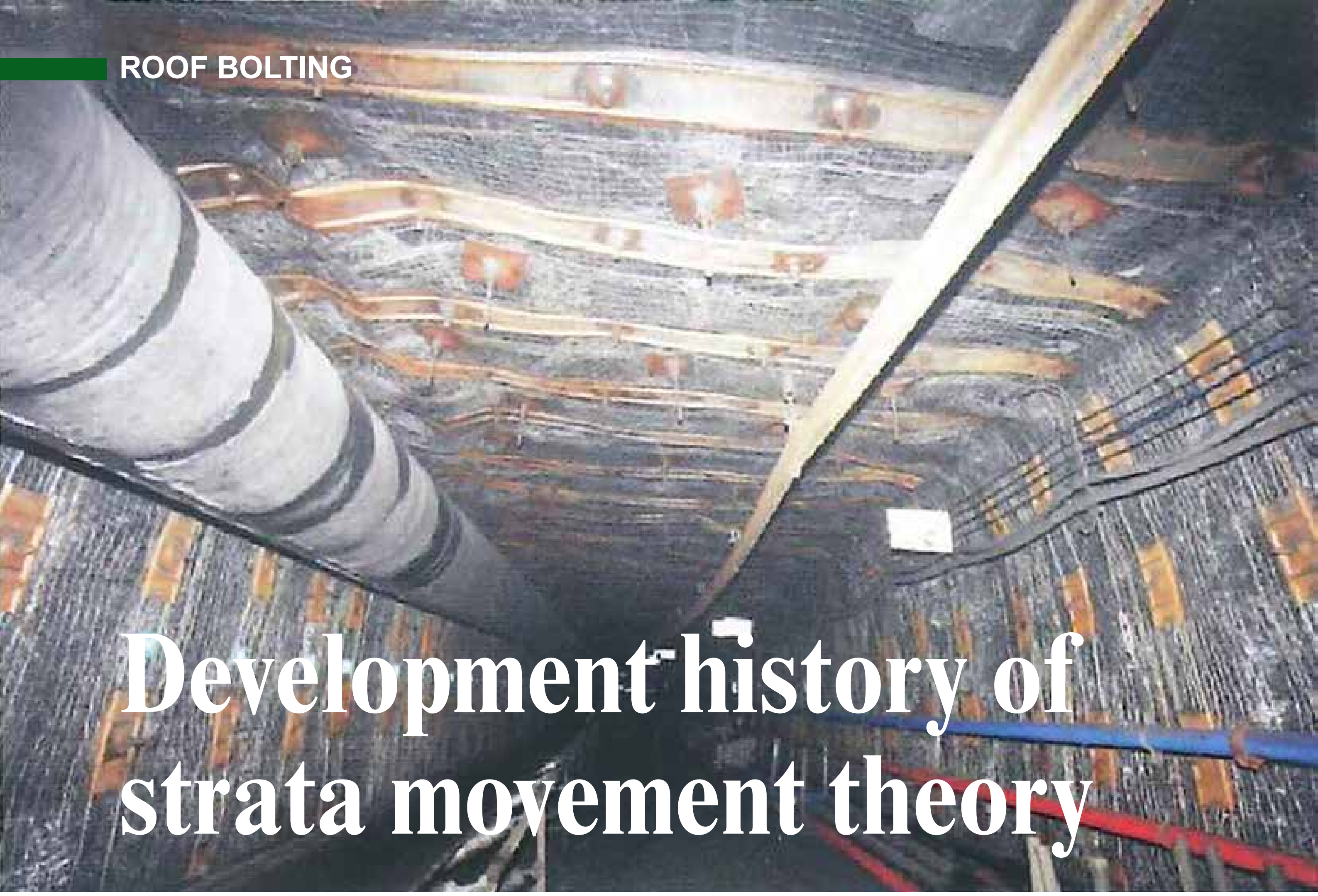
Last year, new workplace standards for electric mining vehicles were introduced. Welton says he's glad the standards introduced voltage range limits for underground mining equipment and provided measures for the operation and maintenance of electric equipment, but says more protocols are needed.

For instance, he notes there are no regulatory requirements in place for charging stations – one potential source of battery fires. Likewise, while Welton notes that manufacturers have been supportive in providing training to the workers using this equipment, he also says training is a "weakness" in the industry.

Cambrian College and Collège Boréal in Sudbury have both started offering industrial battery-electric vehicle maintenance training programs within the last two years. Welton is working with Ontario's Mining Legislative Review Committee to identify areas of need and establish new safety standards for the industry.

"There's different challenges and hazards, especially with the voltage that you're dealing with," Welton said. "It has to be dealt with appropriately."

Tom Welton, the director of health and safety services and education programs at Workplace Safety North, organizes a yearly symposium on battery-electric vehicle safety in mines. (Workplace Safety North)



Development history of strata movement theory

There are many reasons why animals dig into the earth: to find food and water; to make a home; to hide from danger; to store food. People, burrow for all these reasons together with a few of their own. It may be said with certainty that tunnelling was man's first exercise in engineering. The enlarging of the cave where he lived would be an obvious operation to a creature capable of logical thought. In fact, the remains of Stone Age victims of tunnel collapses have been found together with their tunnelling implements.

The accidental discovery of water and mineral deposits during the operation of extending the home led men to bore for that purpose alone, and when tunnelling had developed from an inborn animal instinct to an art it was applied to as many purposes as it is today – which include, in addition to those mentioned, drainage, sewerage, storage, and transport of people, materials and goods.

The understanding of strata movement dates to the 15th and 18th centuries when the impact of underground mining on water resources was discovered. However, the mechanism of damage and movement of overlying strata due to mining was not yet clear.

The dogged perseverance shown by the ancients in their engineering operations was astonishing especially considering the primitive tools and methods they employed. Although the brute-strength-and sweat method was employed for some time, it was the Ancient Egyptians who first applied science with a view to lessoning its labour. These methods were later copied by the engineers of ancient Greece and Rome and were used throughout Europe until the introduction of gun powder for blasting rock.

Over time, research and development in strata movement theory have progressed through various stages, including awareness, preliminary research, theory formation, rapid development, and application innovation. As design methods evolve, new problems not anticipated can arise and today's rock engineers are faced with a new set of problems that must be solved depending on the mining task they face.

Rock is an extremely complex engineering material and designing in rock requires the application of as much science as relevant and as much experience as available alongside as much common sense as possible. Above all, a design must be balanced in that every factor, even those which cannot be quantified, must be considered before reaching a final decision.

With the increasing size and complexity of mining operations worldwide come problems which occur continually and vary in terms of scale, extent, and time. The provision of support and strata control underground forms an essential part of any mining or tunneling operation.

Managing Editor Trevor Barratt chooses Strata reinforcement as a subject for discussion because of its importance in modern high speed rock tunnelling and mining operations and because some of the latest techniques and newly developed materials may not be familiar to our worldwide readership.

STRATA REINFORCEMENT

Since the introduction of rock bolts 40 years ago, their use to support and stabilize openings in U.S. mines has steadily increased. The number of roof falls has been significantly reduced where rock bolts have been installed, and they are now the primary support required by the Mine Safety and Health Administration (MSHA) in most mines. An additional benefit is that rock bolts provide an unobstructed opening for greater freedom of movement and improved ventilation.

However, roof falls still occur even in areas where rock bolts have been installed. While every effort is made to use scientifically gathered data and case study results to design and evaluate safe and economically feasible roof control plans, more information is needed to provide a better understanding of bolt response to strata movement. Not having this information could lead either to under design or overdesign with regard to bolt type, length, diameter, and spacing. Under design may result in roof falls, while overdesign may result in an unnecessary financial burden on a mine operator. Scientific knowledge is needed to describe rock bolt behaviour and to provide guidelines for design of effective roof control plans with respect to safety, economy, and integration with other mining activities. To formulate-such guidelines, instrumented bolts used in investigations of support systems must be capable of providing reliable data.

Numerical modelling is one approach being used by researchers to study the support requirements of strata around underground openings. However, numerical modelling alone is not adequate because not enough is known about the required input parameters and the nonlinear nature of highly stressed rock. Additional laboratory and field experiments are necessary to provide a more complete understanding of support interaction relationships.

Resin-anchored, full-column rock bolts are one type of roof support used to support unstable openings in underground mines. Because the use of these bolts is increasing, improved design criteria and installation techniques will result in more effective support.

In an effort to gain a better understanding of the mechanics involved in the transfer of load between a bolt and the mine rock, a program was started by the U.S. Bureau of Mines to study the load transfer mechanics of passive, fully grouted rock bolts. This work was done in support of the Bureau's goal to improve underground safety for the Nation's miners. The first phase of the study was conducted in the laboratory and was directed to examining the linear, nonlinear, and time-dependent behaviour of bolts under different loading conditions. This provided information necessary for the development of a numerical model. The next task was to establish a correlation between the laboratory test results and grouted bolts installed in an actual mine roof. The load transfer mechanics of fully grouted bolts was then studied in four mines with different immediate roof conditions (Eagle Mine, Craig, CO; Wabash Mine, Keensburg, IL; Galatia Mine, Harrisburg, IL; and Warwick Mine, Greensboro, PA).

After these studies were completed, 12 fully grouted, instrumented bolts were installed in the Cyprus Plateau Starpoint No. 2 Mine near Price, UT, during the development phase of the entry. These bolts were monitored for a year while two longwall panels were mined nearby, and changes in bolt loads were observed throughout the useful life of the entry. Thirteen instrumented bolts were also installed in the tailgate entry for a longwall at Jim Walters Resources No. 7 Mine in Brookwood, AL These bolts were used to observe roof conditions as the longwall was mined.

STRATA REINFORCEMENT TECHNIQUES: OLD AND NEW

The first rock bolts were wooden dowls, driven into formed holes through rock layers, which depended upon frictional resistance and the tensile strength of the wood to hold the rock in place. This technique was introduced into the USA by immigrant tin miners from Cornwall UK, early in the nineteenth century, and from it has developed the rock -bolting techniques of today.

After the second world war various mechanical forms gradually came into use, the best known of these being the mechanical expansion shell bolt that became very popular in the USA. Applying these practices elsewhere worldwide however did not always succeed unfortunately due to the differences in mining systems and the lack of mechanisation.

The search for an economical alternative for the mechanical bolt which would still have the advantage of being easily installed,

and be able to carry a working load within a very few minutes of installation, but which would distribute the stress much more widely in the rock strata, resulted in the development of a number of encapsulated resin systems. The first recorded use of such a system was in Germany in1959, thereafter parallel developments took place in France, in the USA and in the UK.

RESIN-GROUTED BOLTS OFFERED SEVERAL ADVANTAGES FOR ROCK REINFORCEMENT:

1 Quick Support: Resin-grouted bolts harden faster than cement-grouted bolts. This rapid setting time provides immediate support to the rock mass.
2 Long Lifespan: When correctly installed, resin-grouted bolts can provide permanent support with a lifespan of 20 to 30 years. They maintain their effectiveness over an extended period.
3 Corrosion Resistance: Unlike steel bolts, resin-grouted bolts are not susceptible to corrosion. This makes them suitable for harsh environments or areas with water exposure.
4 High Load Capacity: Resin-grouted bolts can withstand high loads due to their strong bonding with the surrounding rock. They effectively transfer load from the rock mass to the bolt.
5 Flexibility: Resin-grouted bolts can be installed at various angles and orientations, adapting to the specific geological conditions. This flexibility enhances their applicability.

Remember that the choice between resin-grouted and cement-grouted bolts depends on factors such as cost, installation time, and project requirements. Each method has its place in rock reinforcement strategies.

In mining and tunneling, anchor grout materials play a crucial role in securing rock bolts and anchors. Let us delve into the properties and types of grouts used for this purpose:

Grouts- Resin or cement

Uniaxial Compressive Strength (UCS):

The UCS is a critical property for both resin-based and cementitious grouts.

Resin manufacturers typically test UCS using 40 mm cubes, while cementitious grouts use 50 mm samples.

The cylindrical shape of resin or grout samples should have a length-to-diameter ratio between 2 and 2.5.

UCS values tend to be higher for cube samples compared to cylindrical ones.

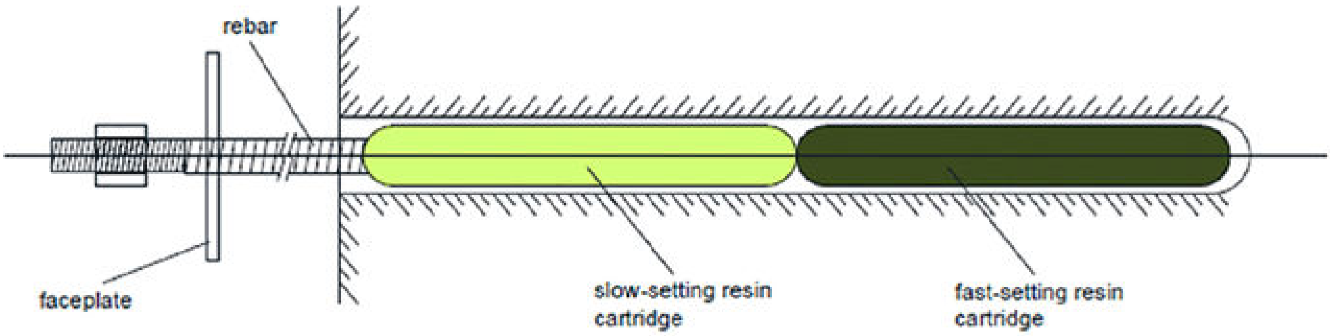


Image of resin grouted bolt showing separation of fast and slow cartridge

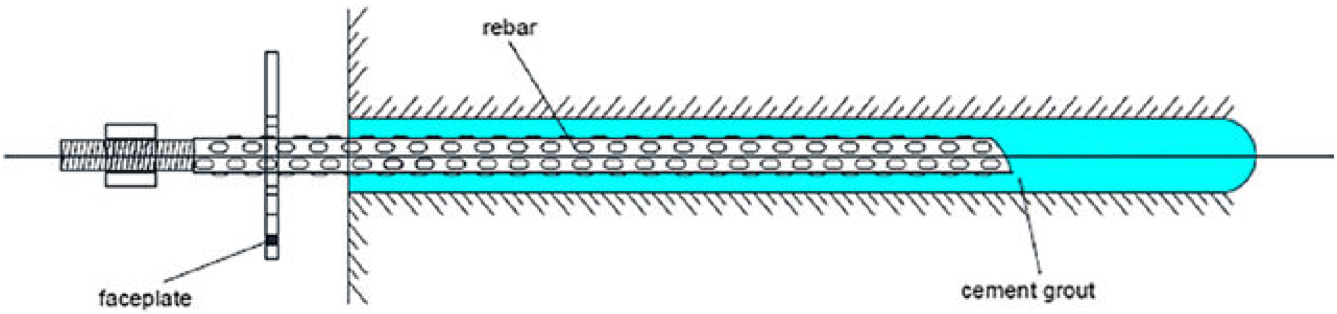


Image of cement grouted bolt

Strength values can vary significantly due to individual casting of samples.

Cure time affects the strength properties.

Cementitious Rock Bolting Grout:
This type of grout is packed in a water-permeable membrane and provides normal setting times.

It compensates for shrinkage and is commonly used for grouting rock bolts and anchors in tunneling and mining.

SUPAgrout for Cables and Long Anchors: SUPAgrout is a mixture of calcium aluminates, masonry cement, pozzolanic fillers, slagment, graded sands, and extenders. It is specifically designed for cables and long anchors.

Grout Anchoring:
Among various anchoring technologies (mechanical, grouting, and friction), grout anchoring is popular due to ease of installation, low cost, and versatility.

Grout anchors are installed via low-pressure grouted boreholes, where the grout permeates through pores or natural fractures in the ground.

More recent developments in Grout anchors include:

Carbon Fiber Reinforced Polymer (CFRP) Anchors:
Advances in corrosion-resistant materials like CFRP have allowed research into more robust anchor systems.

CFRP anchors aim to eliminate limitations encountered with steel strand ground anchors.

These materials offer improved durability and resistance to corrosion.

Single Bore Multiple Anchor (SBMA) System:

Developed as an important innovation in ground anchor technology.

SBMA simplifies installation by using a single borehole for multiple strands.

It enhances efficiency and reduces costs compared to traditional methods.

Remember that selecting the right grout material depends on factors such as rock type, load requirements, and installation conditions, installation time, and project requirements. Each method has its place in rock reinforcement strategies.

MATERIAL DEVELOPMENT AND CONTROL: MONITORING AND SENSORS

Rock bolts as already evident in this article have been widely used as rock reinforcing in underground coal mine roadways and tunnels. Failures of rock bolts occur because of overloading, corrosion, seismic burst, and bad grouting, leading to catastrophic economic and personnel losses. Monitoring the health condition of the rock bolts plays an important role in ensuring the safe operation of underground mines.

Smart sensors
The most widely used smart sensors for rock bolt monitoring are the piezoelectric sensors and the fiber optic sensors. The methodologies and principles of these smart sensors are reviewed from the point of view of rock bolt integrity monitoring. The applications of smart sensors in monitoring the critical status of rock bolts, such as the axial force, corrosion occurrence, grout quality and resin delamination, are highlighted. In addition, several prototypes or commercially available smart rock bolt devices have been introduced.

Piezoelectric Sensors:
Piezoelectric sensors are widely employed for rock bolt monitoring. These sensors generate an electrical charge when subjected to mechanical stress (such as axial force or vibrations).

By measuring the charge, they assess the load on the rock bolt and detect any anomalies.

Fiber Optic Sensors:
Fiber optic sensors use optical fibers to measure parameters like strain, temperature, and pressure. They are highly sensitive and immune to electromagnetic interference.

In rock bolts, fiber optic sensors can monitor axial force, deformation, and grout quality.

Applications:
Smart sensors help monitor critical aspects of rock bolts, including:

Axial Force: Ensuring proper tension.

Corrosion Occurrence: Detecting rust or degradation.

Grout Quality: Assessing the effectiveness of grouting.

Resin Delamination: Detecting separation between the bolt and resin1.

Prototypes and Commercial Devices:

Several smart rock bolt prototypes and commercially available devices incorporate these sensors. These devices enhance safety by providing real-time data and early warnings.

In summary, piezoelectric sensors and fiber optic sensors are the go-to choices for assessing rock bolt integrity and ensuring safer underground mining operations.

Geological conditions (strata type, rock properties, in situ stress, and planes of weakness) play a crucial role in successful roof bolting. Accurate specification of these factors is essential during the design of any roof bolting system.

Water is of critical importance to mining

Industrial water usage continues to be a hot topic, as people, countries and companies around the world seek to address the challenge facing global water security. It is predicted that by 2025, at least two thirds of the world's population will face 'water stress' ; defined as when the demand for water exceeds its availability or poor water quality limits its use. While the future of water security in this sense may seem bleak, it is not foregone, and industrial companies are working toward a more sustainable future for the resource.

Water is of critical importance to mining in particular; most mining operations are in water scare areas and without it, these operations would not be possible. Faced with the conundrum of the need to both use and conserve this precious resource, the responsible management of water by mining companies is more critical than ever. The mining industry is increasingly driving forward to achieve sustainable change and is helping to address the challenge of water shortages faced around the world. Collaboration and investment in innovative technology is key to making a real difference in conserving a source so vital to the world.

Mines require water. At the same time, because many mine working areas are below the water table, the removal of water is a major challenge. Here, we briefly review the concepts of mine water and mine water management as well as the most used pumps for these applications.

MINE DEWATERING AND THE PROCESS

The definition of mine water is that it is not a slurry, i.e. generally it is considered to contain <50g/l of solids. Mine water can be categorised into two different streams of water: removal and addition.

The first category involves the removal of water from the mine area (mine dewatering) and the removal of water from

the process (process dewatering). Mine water originates from several sources. Precipitation from rainwater and subsequent floodwater or melting snow generally affects above-ground mining, whereas underground mines are affected by subterranean waterways, ore bodies containing pockets of water, or the long-term rise of the water table from precipitation.

Conversely, minerals processing requires the addition of water at various stages, and this can either be reclaimed water from within the mine area or, where not sufficiently available, brought in from external sources such as town water, river, or seawater.

The management of water around the mine site is referred to as mine water management and managing the water resources is a critical task and a major challenge in mining. It is a continuous process, and dewatering operations would normally continue when a mine is operating at reduced capacity or even temporarily shut down.

CHALLENGES IN DEWATERING

The primary objective of a mine dewatering system is to keep the mine sites dry to allow for safe and efficient mining. To determine the most suitable dewatering method for a specific type of mine, the following challenges and conditions need to be considered.

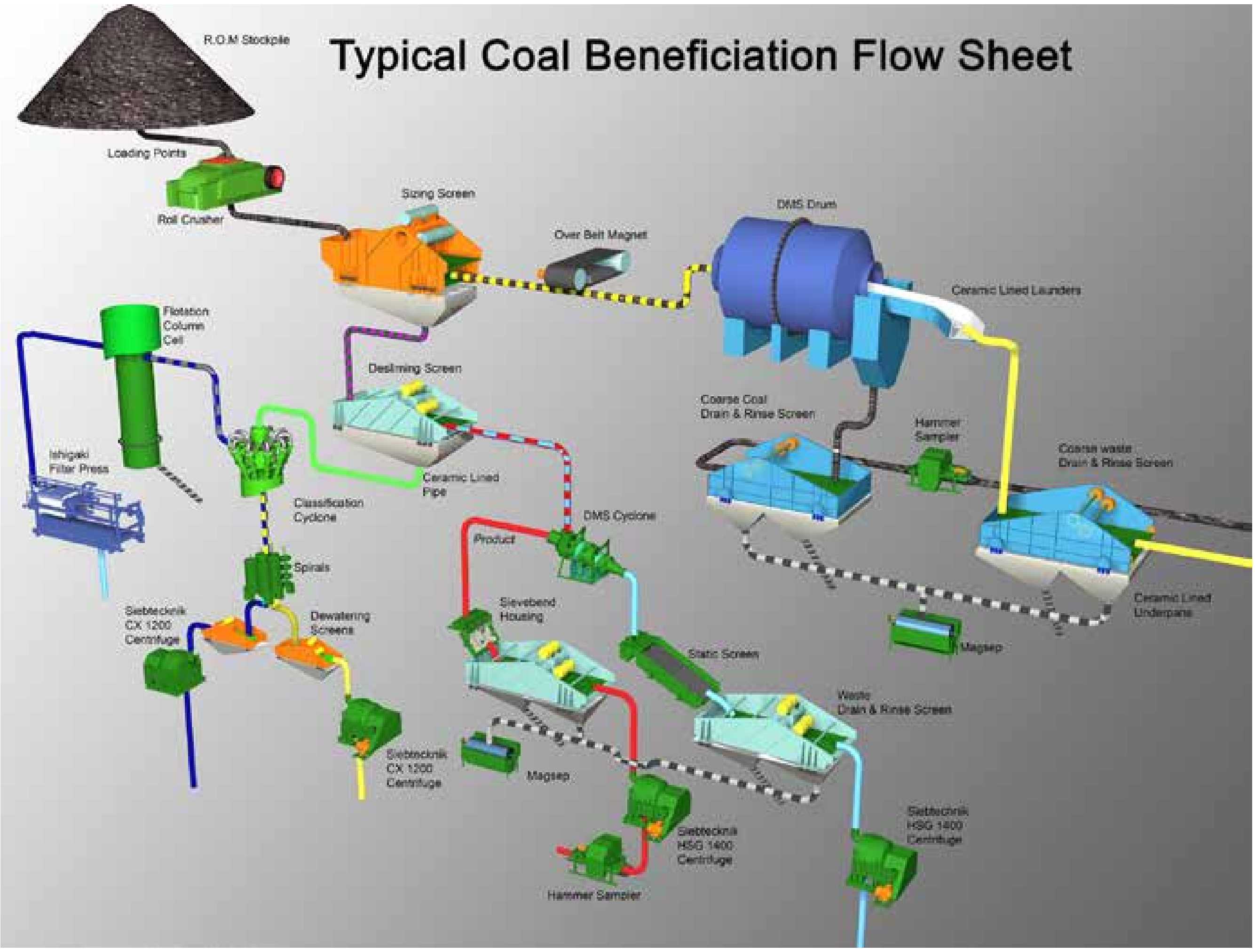
Mine type. This generally determines the best dewatering method but may be overruled by end-user preferences.

- Location. Mines in remote locations may have reduced access to adequate electrical power. Therefore, alternate technologies need to be considered.
- Incoming volume of water. It is of critical importance to have an accurate estimate of the inflow from all possible sources.
- Mine depth. Whether open pit or underground, the mine depth will determine whether single-lift drainage or a stage pumping system needs to be employed.
- Water properties. This will determine the dewatering system, pump technologies and materials of construction. The type of pumps used depends on various factors, including water quality, chemical composition, and solids content.
- Life of mine. If the expected mine life is long, a more permanent system needs to be considered. In a mine with a shorter life span, portable products or a less costly dewatering system can be used.
- Cost budget. The budget available for the dewatering system defines which methods can be considered.

WHAT IS MINE DEWATERING?

There are two main types of mine dewatering, i.e. active and reactive (or passive). Active dewatering is a process used mainly around open-pit mines to lower the water table. It reduces ingress and seepage of water into the mine areas, allowing safe and uninterrupted work. The technologies used are multi-stage deep well pumping or well-pointing.

Reactive dewatering is used to remove water from working areas and applies to both open-pit and underground



mines. Multiple pump technologies can be used in these applications, including submersible, vertical, end-suction, multistage or volumetric pumps. The pump type and construction materials depend on various factors, such as water properties, the presence of abrasive solids, the concentration of solids and the location of the installation.

WHAT IS PROCESS DEWATERING?

Process dewatering generally refers to the separation of water from solids towards the later part of mineral processing. Slurry pumps are normally used for pumping the process water to various types of filters or into thickening and settlement tanks.

WHAT IS PROCESS WATER AND TREATMENT?

Large quantities of water may be required in mineral processing. The quality of the water is highly important and therefore some level of treatment is needed before it enters the process. A combination of vertical, horizontal, and submersible pumps may be used in the treatment process, and the water source, e.g. seawater, reclaimed water, etc. may affect the materials of construction used. The treated water is then added to the process at various stages.

INTAKE WATER TECHNOLOGY REQUIREMENTS

Because intake water stations may transport water into the mine from various types of sources, the technology requirements will vary accordingly. Vertical turbines and horizontal end-suction pumps are most used, depending on the pump station design and configuration.

RECLAIMED WATER AND REUSE

The scarcity and cost of water means that reclaiming and reuse are on the increase. Water is reclaimed from tailings ponds, lagoons and the downstream of minerals processing by vertical, horizontal, and submersible pumps. It is treated before use.

Water may be a nuisance, but it is also essential for the mining process. The management of this precious resource is of critical importance. Sulzer offers a comprehensive portfolio of innovative pumps and agitators for mining applications, from lightweight and robust submersible dewatering pumps to wear-resistant high-lift centrifugal pumps for the removal of sludge, mud, silt, and water in abrasive and corrosive environments.

COAL FINES SLUDGE DEWATERING

The Yancoal Australia Hunter Valley Operations (HVO) is a multi-pit open-cut mine producing more than thirteen million tonnes of thermal coal and semi-soft coking coal using dragline truck and shovel methodology. The raw coal that is mined is called the run-of-mine (ROM) coal is delivered to the Coal Handling and Preparation Plant (CHPP).

Typically, 17-20% of the ROM coal delivered to the CHPP is considered waste. This facility washes the coal of soil and rock,

crushes it into graded sized coal, stockpiles and prepares it for transport to market. The more of this waste material that can be removed from coal, the lower its total ash content, the greater its market value and the lower its transportation costs.

After being washed and prepared for sale, the coal is loaded onto trains for transportation 90 km to the Port Waratah Coal Terminal in Newcastle where it is shipped to international customers.

The waste slurry from the CHPP, is directed into settling ponds or tailings dams, however, to reduce waste, many mines recover the coal fines for further processing. The slurry can either be processed in a series of centrifuges and cyclones to remove water and separate the coal fractions however this is an expensive mechanical process. An alternative is to use dewatering technology using Geotube dewatering containers and Yancoal Australia decided this was the best option for the HVO north pit at Ravensworth.

The settling pond was approaching a level that meant it could no longer accept further solids without the risk of overflowing. Consequently, Dredging Systems Pty Ltd was engaged to remove the sludge so that the coal fines could be recovered. A small dredge was used with a rotating cutting head on the inlet pipe. This enables the sludge to slurry in the base of the pond and enables the collection of solids to be accelerated.

The sludge was then pumped into eight Geotube dewatering containers supplied by Geofabrics Australasia. These tubes, contained in a large bunded area adjacent to the settling pond, had a circumference of 36.6 m and were 30.6 m in length with capacity to retain a dry volume of approximately 1,000 m3 of dry cake.

Each tube was connected via a pipe manifold system so that as one Geotube reached its maximum fill height, the valves could re-direct the pumped slurry into the next tube. As each Geotube cycled through pumping and dewatering sequences, the containers progressively retained the coal fines up until each tube could no longer accept further solids without extending beyond their maximum fill height. Effluent water from the tubes was returned to the settling pond via channels inside the bund wall surrounding the Geotube containers.

Each Geotube container was supplied with two filling ports. These ports could either be a fabric port or one with a PVC Geoport reinforcing collar. In this instance, due to the size of the containers, PVC ports were supplied. Lay-flat hoses were used to connect into these ports to maximise flexibility of the hoses as the Geotube is pumped into and the Geotube inflates without putting strain onto the filling port.

Often, polymers are added into the manifold pipework which enables very fine colloidal fractions to form a

floc and promotes rapid separation of water from solids to accelerate the dewatering process. In the case of the HVO pond, the addition of polymer was not required, and the process progressed at a satisfactory rate. After three months, the retained solid material within the Geotube containers had sufficiently dewatered allowing the Geotube to be split open and the 'cake' easily removed using a loader and sent for processing and on-sold.

MARKET OVERVIEW:

The global mining pump market is projected to grow from USD XX million in 2022 to USD XX million by 2030, at a CAGR of 7.7%. The growth of the market can be attributed to the increasing demand for minerals and metals across the globe. Moreover, rising investments in mining activities are also fueling the growth of the market. The global mining pump market is segmented based on type, application, and region. Based on type, it is divided into small (up to 500 gpm), medium (500-1000 gpm), and high (more than 1000 gpm) pumps. Based on application, it is classified into drainage, gravel/dredge slurry transport systems, jetting systems, water/wastewater treatment systems, and other applications including dewatering & solidification processes, Geographically speaking, it covers North America, Latin America, Europe, Asia Pacific, and Middle East & Africa. Some key players operating in this industry include Weir Group PLC., Flowserve Corporation., Grundfos Holding A/S., KSB Aktiengesellschaft., and Sulzer Ltd.

PRODUCT DEFINITION:

Mining pumps are devices which are used to extract water from a mine. They are an important part of the mining process as they help to remove groundwater and other liquids from the mine so that the miners can work safely.

SMALL (UPTO 500 GPM):

Small (up to 500 gpm) is the most commonly used pump in the mining industry. It has wide application in raising water for hydraulic fracturing, drilling mud systems, and well-completion treatments. The small size of these pumps allows them to be used under extremely high-pressure conditions which are around 2-3 times greater than atmospheric pressure. This factor makes it suitable to use in underground mining applications where large-capacity pumps would not fit due to space constraints or other operational limitations.

MEDIUM (500-1000 GPM):

The medium (500-1000 gpm) segment is anticipated to witness growth over the forecast period owing to its increasing demand in the mining pumps market. The medium pump has a capacity between 500 grams per minute and 1 kg per minute. It is used for discharging water from mines, dams, canals and construction sites among others.

HIGH (MORE THAN 1000 GPM):

A high (More Than 1000 gpm) of mining pump is a high-pressure water jet that can be used to extract minerals and other materials from the ground. The advantages of using a high-pressure water jet over traditional methods include faster extraction times, reduced labour costs, and increased efficiency.

APPLICATION INSIGHTS:

The drainage application segment accounted for the largest share of over 40% in 2019. The demand is expected to be driven by the growing construction industry, which requires large-scale mining operations to be carried out efficiently. Drainage systems are also required in case of emergencies or natural disasters, which further drives up demand. The gravel/dredge application segment is expected to grow at a CAGR of 3.5% from 2022 to 2030 owing to rising gold production across various countries such as Australia, Brazil and Canada among others.

REGIONAL ANALYSIS:

The Asia Pacific dominated the global mining pumps market in terms of revenue with a share of over 45.0% in 2019. The region is expected to witness significant growth owing to increasing demand for drainage pumps and water/wastewater pumping equipment across various industries, such as construction, mining, power generation, and chemical processing. In addition, rising investments by multinational companies in developing mineral resources are anticipated to fuel product demand over the forecast period.

The growing number of mines globally has led to an increase in metal production from 2018 to 2019; however, there was a decline from 2017 to 2018 due to decreasing consumption levels across most major end-use sectors including automotive and consumer electronics resulting in lower industrial outputs (mining industry). However, since 2019 metal prices have increased leading towards higher industrial outputs which will result in increased consumption levels thereby driving the market growth during the forecast period (2022 - 2030).

GROWTH FACTORS:

- Increasing demand for metals and minerals from various industries
- Growing urbanization and industrialization in developing countries
- Rising investment in the mining sector by public and private players
- Technological advancements in the pumps manufacturing industry
- Stringent environmental regulations to promote the use of energy-efficient pumps

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NEWS, PLANT AND EQUIPMENT

B.C.'s coal industry not worried about G-7's phaseout plan

B.C.'s mining sector is not concerned after Canada joined six other western countries in the phase-out of "existing unabated coal power generation" by 2035.

Michael Goehring, president, and chief executive officer of the Mining Association of British Columbia said the agreement impacts thermal coal – coal used in electricity generation.

"B.C. only produces steelmaking coal (or metallurgical coal) that is currently necessary for the production of steel," Goehring said. "The G-7 decision does not have an impact on steelmaking coal, which is currently listed as a 'critical material' in the European Union."

British Columbia is Canada's largest producer of coal, accounting for 59% of all Canadian coal exports as of 2022/ It is also Canada's largest exporter of steelmaking coal, and coal consistently fetches the highest returns relative to other mined exports. In 2022, for example, coal accounted for 67% of all B.C.'s mineral production valued at $18.2 billion with copper (17.8%) a distant second.

B.C., however, has had a history of thermal coal production, and thermal coal produced in other provinces ships to global markets through B.C. with most shipments going to Asia.

Steelmaking coal production is expected to range between twenty-four million to twenty-six million tonnes, up from 23.7 million tonnes in 2023, according to a guide issued by Teck Resources January. Production is expected to remain at these levels throughout 2025 to 2027, the company noted. Canada, led by B.C., accounted for 2.4% of global steelmaking coal production in 2022.

Environmentalists point to thermal coal's contribution to climate change. The emergence of cheaper alternative energy sources such as wind and solar power has raised questions about the economics of thermal coal, and several leading energy companies are getting out of the thermal coal business.

B.C. does not burn thermal coal for power, but four Canadian provinces do. Coal contributed to 51% of energy produced in Alberta and 30% in Saskatchewan in 2021, followed by Nova Scotia (15%) and New Brunswick (four%).

B.C.'s Energy Minister Josie Osborne said the announcement from the G-7 is in line with Canada's earlier promises to phase out thermal coal by 2030.

"So, I am encouraged to see the decision from the G-7, and it is a positive signal that industrialized countries are sending to the rest of the world about decreasing about our dependence on thermal coal. It is heavily polluting, and we have alternatives," Osborne said.

Osborne pointed to the ongoing use of thermal coal by countries like China and India. These two accounted for almost 61% of total global production

Meanwhile, several western countries are testing technologies to replace steelmaking coal with hydrogen in the production of so-called green steel.

Osborne said that technology is still under development and steelmaking coal remains in high demand.

"(Steelmaking coal from B.C.) is still going to be an important commodity for years to come."

The G-7 consists of Canada, Germany, France, Italy, Japan, the United Kingdom, and the United States.

Design and research on power systems and algorithms for controlling electric underground mining machines powered by batteries

This article discusses the work that resulted in the development of two battery-powered self-propelled electric mining machines intended for operation in the conditions of a Polish copper ore mine. Currently, the global mining industry is seeing a growing interest in battery-powered electric machines, which are replacing solutions powered by internal combustion engines. The cooperation of Mine Master, Łukasiewicz Research Network – Institute of Innovative Technologies EMAG and AGH University of Science and Technology allowed carrying out a number of works that resulted in the production of two completely new machines. In order to develop the requirements and assumptions for the designed battery-powered propulsion systems, underground tests of the existing combustion machines were carried out. Based on the results of these tests, power supply systems and control algorithms were developed and verified in a virtual environment. Next, a laboratory test stand for validating power supply systems and control algorithms was developed and constructed. The tests were aimed at checking all possible situations in which the battery gets discharged as a result of the machine's ride or operation and when it is charged from the mine's mains or with energy recovered during braking. Simulations of undesirable situations, such as fluctuations in the supply voltage or charging power limitation, were also carried out at the test stand. Positive test results were obtained. Finally, the power supply systems along with control algorithms were implemented and tested in the produced battery-powered machines during operational trials. The power systems and control algorithms are universal enough to be implemented in two different types of machines. Both machines were specially designed to substitute diesel machines in the conditions of a Polish ore mine. They are the lowest underground battery-powered drilling and bolting rigs with onboard chargers. The machines can also be charged by external fast battery chargers.

INTRODUCTION

The concept of working machine drive based on an electric motor or internal combustion engine, i.e., the obtaining of mechanical energy that can be used to drive the carriage system of the machine and its working systems, refers to complete drive units. Both internal combustion engines and electric motors have been known and successfully used for many years in stationary and mobile machines. However, electric motors do not consume oxygen and do not emit exhaust fumes, which has a positive effect on the environment and human health[1]. They do not generate as much noise, and their efficiency reaches the level of more than 90% or even 98%, so they generate much less heat. In addition, the electric drive unit is less complicated[2]. Therefore, wherever mains power can be used, the electric drive wins. In the case of vehicles, mobile machines, or machines working far from the source of power supply, the internal combustion engine is commonly applied. However, if we want to use battery power, which is also referred to as battery drive, additional serious problems arise. The major drawback of battery power supply is the limited range or limited operating time of the machine, especially when we take into account the long charging time. The use of additional electrically powered systems, such as lighting, air conditioning, or a mechatronic system, further shortens the working time. The key issue in the case of such machines is, therefore, to manage and control the battery condition as well as to optimize battery supervision systems[3]. In the case of underground mining, the operating time reduction due to low temperatures is not the only problem. Apart from the technical aspects, economic considerations related to the cost of purchase and battery operation are also extremely important[4,5].

Very important factors related to the underground mining of metal ores are the costs involved in the ventilation of workings and the negative impact of substances produced during combustion of liquid fuels by the machines on the health of the working staff. In order to reduce costs and improve the working conditions of the workers, it is advisable to replace diesel engines with electric motors powered by the mains and battery. Such a tendency is observed in many countries around the world, with Canada being the precursor[2,6]. This applies in particular to self-propelled mining machines, such as drilling and bolting rigs, LHD loaders, and haul trucks. It should be emphasized, however, that the user expects electrically driven machines to have the same parameters and functional properties as the ones powered by internal combustion engines. This is a serious challenge because battery power still remains a new issue despite the fact that the electric drive is known and widely used also in mining machines. In addition, it should be noted that the difficulty results mainly from the specific conditions of underground mining and related requirements.

The electric drive of mains-powered vehicles and working machines have been used in industry for many years. It is applied not only in trams, trains, stationary machines, cranes or gantries, but also in those working machines that move in a limited area or at a low speed, or in machines that are transported to various workplaces and can be powered by electrical energy supplied by a cable or pantograph, so the output or time of operation are practically irrelevant. Selected examples include the Metso Nordberg NW 80 semi-mobile crushing set, the John Deere autonomous farm tractor with a cable reel, the CAT 7495 cable excavator, the Hitachi ZE85 excavator, or the Hitachi EH4000AC3 dump truck, which is powered by a pantograph. These are, of course, only selected examples of electric working machines. In addition, in underground mining, electric machines powered from the mine's mains are used wherever it is possible.

Of course, mobile machines pose a challenge, as opposed to stationary machines, such as belt conveyors, fans, or even transfer points, i.e., grids. Typical electric and mains-powered underground mining machines are also longwall shearers and roadheaders as well as narrow-gauge loaders, which operate in a limited area. Typical mobile electric machines include haul trucks and loaders, which are powered by mains and are therefore equipped with a cable reel. Examples include the Aramine L150E mini loader for narrow excavations, the Sandvik LH514E loader, the Epiroc Scooptram EST1030 loader, and the Philips HC12BE dump truck. Battery-powered electric working machines are widely used in a variety of industries. The best known are passenger cars, trucks, or increasingly used electric buses, but in the case of these machines, we have practically only a chassis without demanding working systems, and the working conditions are completely different. However, among heavy working machines that perform various processes, there are also battery-operated versions, especially excavators or agricultural machines, including tractors.

In underground mining, due to very difficult working conditions and high requirements, battery-powered machines began to be designed and used relatively late, mostly in the last three years. Currently, several manufacturers have selected solutions of battery-powered machines that are designed to work in various conditions:

- Aramine – L140B miniloader[7]
- Artisan vehicles (since 2019, it has belonged to Sandvik) A4 and A10 loaders, Z50 haul truck[8]
- Epiroc (until 2018 Atlas Copco – Boomer M2 and E2 drilling rigs, Boltec M and E bolting rigs, Scooptram ST14 loader, Minetruck MT42 haul truck, Easer L, Simba M4, M6, and E7 raiseboring rigs[9]
- Komatsu (do 2017 Joy Global – several models of haul trucks[10]
- MacLean Engineering – more than 20 models of auxiliary machines[11]
- Normet – a few auxiliary machines[12]
- Phillips Machine – haul trucks[13]
- Sandvik – LH518B loader, DD422iE drill rig, LZ101LE bulldozer[14]

Global companies Komatsu and CAT have announced that in the nearest time, they are going to roll out battery-powered machines, such as drilling and bolting rigs[15], as well as the LHD loader[16].

In the case of drilling, bolting, and auxiliary rigs, the working process is for some time carried out in one place; therefore, the most common solutions are usually applied to charge the battery at the workstation. On the other hand, LHD haul trucks and loaders are in motion most of the time, hence the use of quick battery replacement systems combined with quick charging or quick charging without replacing the battery. Additionally, braking energy, which recharges the batteries, is quite often recovered for all types of battery-operated machines[2]. Braking energy recovery is applied not only in self-propelled mining machines on a wheel-tire chassis but also in cog-wheel railways used in coal mining[17].

The results of simulation tests, however, show the advantage of fast charging, especially in long-term operation. In one of the studies[18], the authors have demonstrated that in the case of five-year operation, fast charging is more advantageous from the point of view of the efficiency and operating costs of machines. It is therefore advisable to use an onboard charger, with the possibility of charging from the mains at the workplace and the function of braking energy recovery. In addition, the machine can be charged with external high-power chargers.

Designing machines for underground mining necessitates the use of modern methods that make it possible to meet the requirements of users, taking into account extremely difficult working conditions[19,20]. The battery power supply of machines is an additional design and economic challenge[21]. Other challenges in the design of modern machines intended for underground operation include aspects related to occupational health and safety, among others the problem of excessive noise, which is increasingly often discussed[22], but also the rapidly developing robotization and automation[23] as well as digitization[24,25].

The works carried out in cooperation with Mine Master, Łukasiewicz Research Network – Institute of Innovative Technologies EMAG and AGH University of Science were used in the design of two self-propelled mining machines, namely a drilling rig and a bolting rig. Self-propelled drilling and bolting rigs perform drilling and bolting, which belong to basic cutting processes applied in the room and pillar mining system. In the case of these machines, the above-mentioned processes determine the working system's power demand. The bolting process is necessary and allows controlling the excavation stability[26,27]. Drilling is performed in the case of both drilling and bolting rigs. The energy consumption and efficiency of the drilling process depend on many factors, especially on the drilling method, hole diameter, type and condition of the tool, as well as the physical and mechanical properties of the mined rock[28,29].

Both machines were manufactured and tested. Bench and operational tests were carried out. The tests, which were mainly focused on the functional properties of battery power supply, confirmed the correctness of the developed power systems and operation algorithms. Technical data and additional information can be found in the catalog on the website of the manufacturer (Mine Master Spółka z o.o., Poland, Wilków)[30]. It should be clearly emphasized that these are the first machines in the world designed for low headings.

The Roof Master RM 1.8KE bolting rig is 1.8 m high, whereas the Face Master FM 1.7LE drilling rig has a height

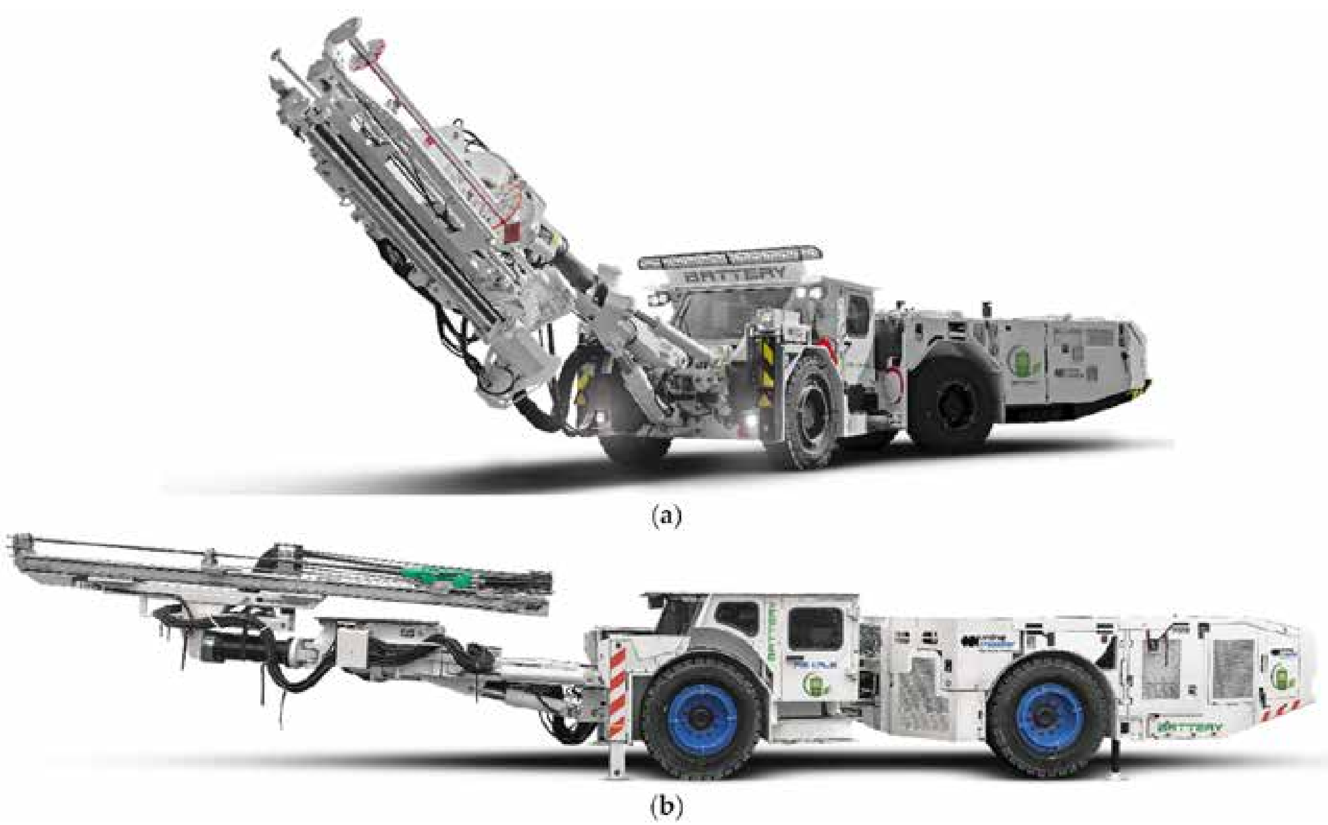


Figure 1: Mine Master battery-powered electric self-propelled mining machines: (a) Roof Master RM 1.8KE bolting rig, (b) Face Master FM 1.7LE drilling rig.

of 1.65 m (**Figure 1**). They can be maneuvered in workings having a width of 4.5 m in the room and pillar mining system. It should be emphasized that both machines have been equipped with onboard battery chargers, which enable direct charging from the mine's mains. The aforementioned solutions of the competing companies require excavations with dimensions considerably exceeding 2 or even 3 m.

The subject of mining battery machines has been widely discussed in recent years at various conferences and in scientific journals. Manufacturers are offering more and more new solutions to battery-powered mining machines that are designed for specific operating conditions[31]. Due to the necessity of charging, these machines must be adapted to the power grid of the future user. Detailed information on the settings and parameters of power systems and control algorithms still remains the "know-how" of their manufacturers. General control algorithms for a typical cycle of discharging and charging a battery can be found in various variants in numerous studies.[32,33]. Especially in recent years, research has been conducted on modern regulators and artificial intelligence[34,35]. There are also algorithms that take into account other systems, for example, hybrid, charging with solar panels or wind turbines[36,37].

The main problem was to design machines specially for a Polish ore mine that could substitute currently operated diesel machines. However, battery-powered machines are different, and it was necessary to carry out underground tests in the mine to specify detailed requirements concerning power systems and control algorithms. One of the biggest challenges was to design very low machines equipped with onboard chargers and the possibility of using external fast chargers. As stated before, both machines are considerably lower than 2 m, which is a significant achievement compared to competitor products.

The above-quoted selected items relate to machines working overground, especially vehicles. Studies on underground battery-powered low machines, in particular those regarding power systems and control algorithms, are unavailable. The existing research and experiences concern battery-powered solutions applied only in overground machines, so they are not useful in the discussed case. Due to various reasons, only some types of batteries, power systems, and components can be used in underground mine conditions. Batteries pose the biggest problem. It is possible to use many different batteries, such as lead acid (VRLA), nickel cadmium (NiCd), lithium iron phosphate (LFP), lithium nickel manganese cobalt (NMC), lithium nickel cobalt aluminum (NCA), and sodium nickel chloride (Na-NiCl2). Sodium nickel chloride (Na-NiCl2) batteries are the best solution for many reasons, including in particular the risk of explosion and fire, operating temperature, ventilation, and durability. In the case of other components, the manufacturers' recommendations regarding operating conditions are applied[2]. This is an important issue in underground mining machines, which needs to be further explored.

MATERIALS AND METHODS

For each newly designed underground mining machine, it is necessary to define requirements based on the working conditions and the user's expectations. This is particularly important in the case of a completely new solution, such as battery-powered self-propelled electric mining machines. The working conditions and user's requirements are different for each mine. Therefore, the first stage of works involved carrying out underground research, which consisted of recording selected parameters of machines. The recorded and analyzed data, as well as the collected comments and requirements of the future machine user, were used to develop assumptions and guidelines for the designed power system along with control algorithms. Next, power systems and control algorithms were developed and checked in simulation tests in a PLC environment. During the research, the properties of various types of batteries, as well as the structure and parameters of the systems managing their operation, were considered. The control algorithms developed as part of the described tests take into account the requirements resulting from the machine operation schedule with the distinction of basic cycles such as standby, ride, operation, and the adopted concept of the drive system. In order to carry out further investigations, it was necessary to design and construct a laboratory stand allowing for the simulation of the machine load and battery discharge, mains battery charging, and braking energy recovery. Tests were performed for all possible combinations of parameters.

The analysis was carried out for typical cases and situations where the braking energy was recovered for a fully charged battery or the battery was charged during the work of the machine operational systems. The performed validation confirmed the correctness of the developed power systems and control algorithms that were used in the self-propelled drilling rig and self-propelled bolting rig. The operational tests of the manufactured machines also proved the correctness of the power systems and control algorithms.

UNDERGROUND TESTS OF MACHINES WITH A COMBUSTION ENGINE

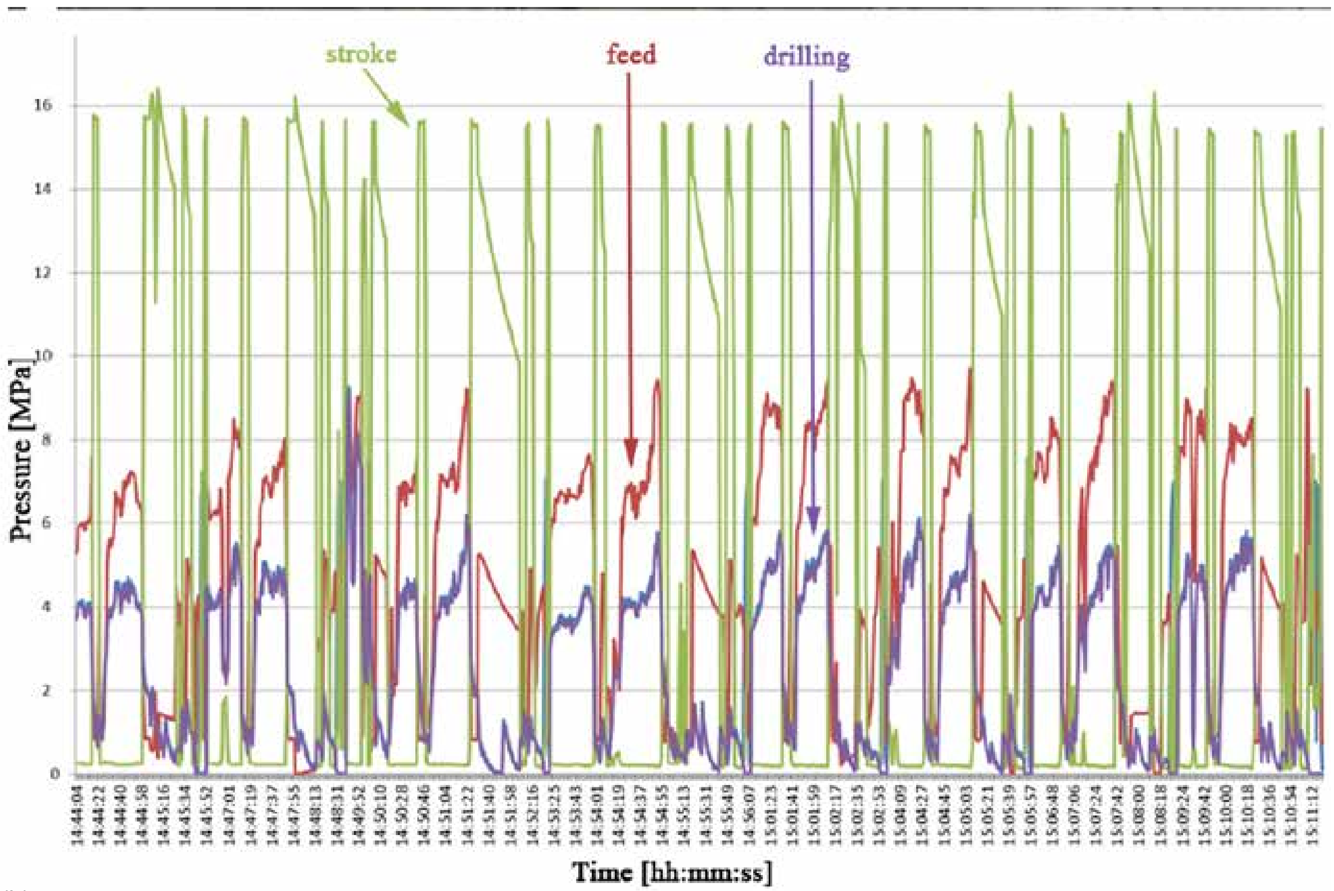
Underground tests were carried out for two internal combustion machines, the operational parameters of which were similar to the planned battery-powered machines. The Roof Master RM 1.8 bolting rig (**Figure 2a**) and the Face Master FM 1.7 drilling rig were used for tests. The tests were conducted in the KGHM Polska Miedz´ S.A. mine O/ZG Polkowice-Sieroszowice. The parameters of the drive system were recorded during the machine ride, while the parameters of the working process and pressure in the hydraulic system of the working parts were recorded during operation (**Figure 2b**). The data were recorded during the drilling and bolting process as well as during rides to other workstations and to the repair chamber.

Figure 2 presents a selected photo from the tests and an example of a graph of pressure courses versus time.

Based on the analysis of the test results and the user's requirements, the following was determined:

- Typical schedules of machines operation;
- Actual parameters of the supply network;
- Speed of movement of machines, taking into account

(a)



(b)

Figure 2: Underground tests in the KGHM mine: (a) Roof Master RM 1.8 diesel bolting rig, (b) recorded pressure courses in the turret hydraulic system.

- the slope and quality of the ground;
- Profile of the route covered by the machines;
- Resistance to movement for various routes and floor conditions;
- Power demand for individual phases and operating conditions.

The performed analyses allowed developing a detailed concept of a self-propelled vehicle with an equivalent electric drive powered by batteries.

POWER SYSTEM OF THE DRILLING AND BOLTING RIG

One of the most important systems in the designed machine is the electric power system. It is the electric power supply system that the mobility of the machine, and, in consequence, its working parameters and performance characteristics, depend on. The main electric circuit (high-current) has been designed to have the same configuration for the drilling and bolting rig. The only difference is in the size of the main engine, battery, or hydraulic systems. Based on the assumptions resulting from the functionality of the machines in the combustion version, a power system was designed, the schematic diagram of which is presented in **Figure 3**.

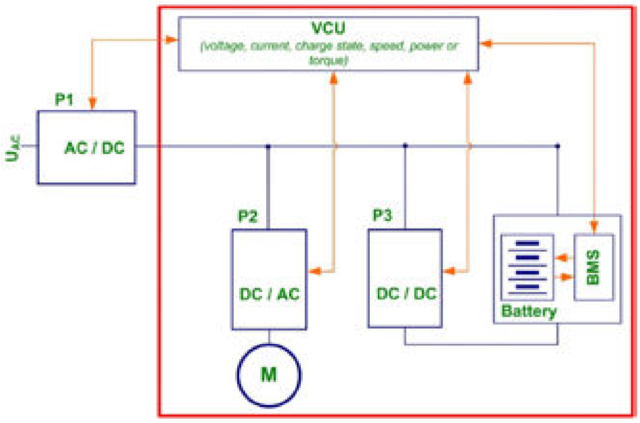


Figure 3. Schematic diagram of the machine power system.

The system is composed of three converters P1, P2, and P3. The P1 converter is used to connect the AC (alternative current) network to the DC (direct current) bus on the machine. For standard network parameters, the rectifier will work in the passive mode, which consists of rectifying the voltage. Improvement in the active mode is achieved by installing an LC (inductor-capacitor) filter on the inverter input. The P3 converter is used to charge the battery, while the P2 inverter is used to supply and regulate the main drive motor M (controller). The control is effected by the VCU (vehicle control unit), which contains a PLC (programmable logic controller) with a program for controlling the machine.

The P2 converter is used during the ride. The P3 converter connected to the battery uses the DC/DC application and operates in the VCM (voltage control mode) with the option of maintaining the voltage on the DC bus side. The P2 converter supplying the drive motor operates in the DC/AC mode at that time. The diagram of the system during the machine's ride has been shown in Figure 3 (red frame).

During the machine's ride, the engine draws power only from the battery. A significant advantage is the energy return to the battery during the downhill ride.

Battery charging and operation take place in accordance with the system shown in Figure 3. Owing to the battery charger incorporated in the machine, it is charged directly from the mine's mains. The work of both machines in the excavation, i.e., drilling and bolting, is always carried out when the machine is connected to the mine's mains. In practice, however, voltage drops may occur in the power supply station, which results in a break in the machine's operation. To prevent these interruptions, the possibility of supplying the hydraulic system with a battery has been provided in the system. In the case of very difficult conditions occurring in the process of hard rock drilling, it is possible to use battery power with increased power on the main motor.

According to the assumptions, the ride is battery-powered. The power consumed by the motor is the power from the battery, decreased by losses in the converters. The power flow during the machine ride is shown in **Figure 4** (red line).

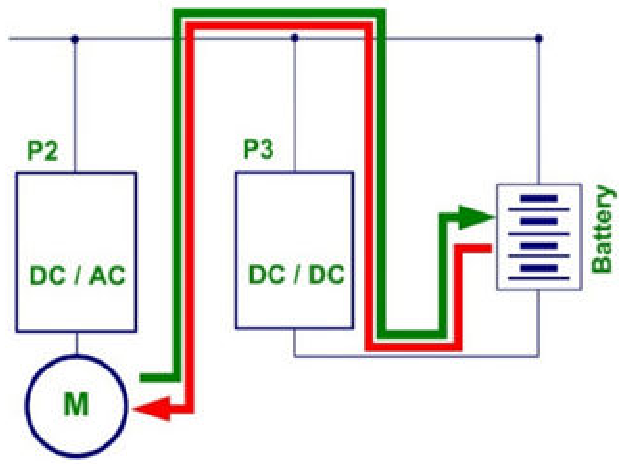


Figure 4: Diagram of power flow during the machine ride (red) and braking (green).

During the ride, energy will always flow from the battery to the main motor. In the analyzed cases, the losses from the converters were not taken into consideration when developing the power flow diagrams. The losses are converted into heat and carried away by the cooling system. Braking is an important element of the machine's ride, which affects its safety. The main role in this process is played by dynamic braking with the option of main motor braking with energy return to the battery. Battery charging must always finish with a certain reserve so that the battery has some capacity to receive the braking energy. The power flow during braking is shown in **Figure 4** (green line). Power flows from the motor to the battery.

The battery is charged near the power supply station or in the repair chamber. Charging takes place via the P1 and P3 converters. Charging energy from the mains is stored in the battery. **Figure 5** (green line) shows power flow during charging.

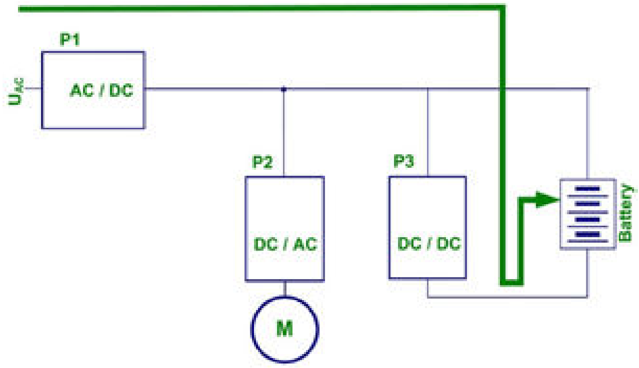


Figure 5: Diagram of power flow during charging of the machine.

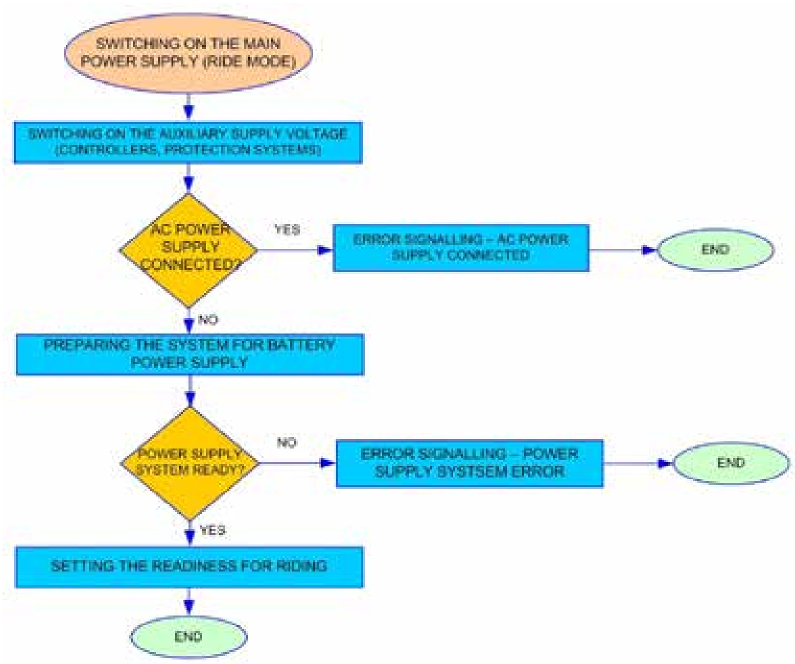


Figure 6: Algorithm for the procedure of switching on the supply voltage in the ride mode.

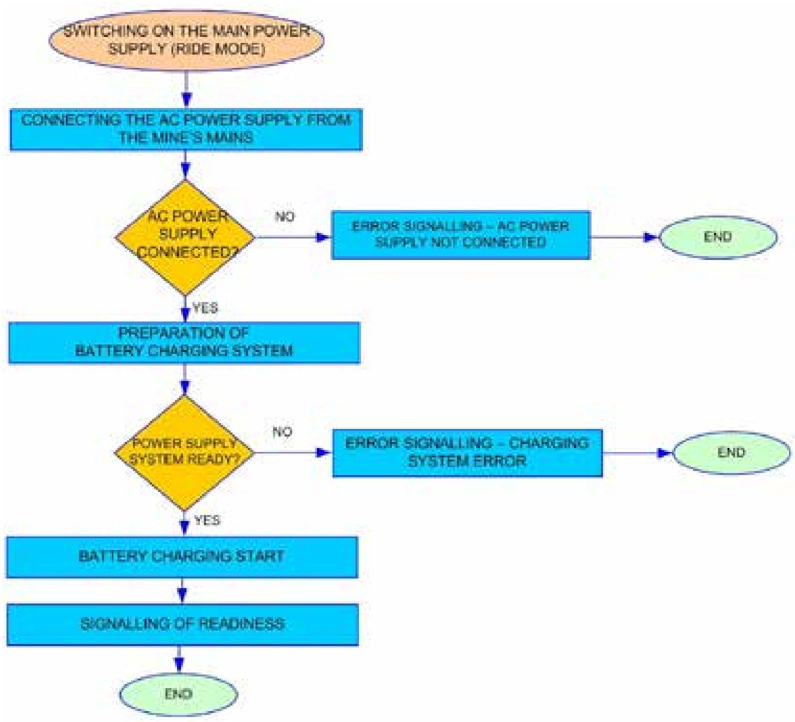


Figure 7: Algorithm for the procedure of switching on the supply voltage in the operating mode.

After the machine has arrived at the workstation, it is possible to recharge the battery in the time between the drilling of subsequent holes or between the installation of subsequent bolts, or during the auxiliary processes. This allows using the machine's working time more efficiently. The master control system controls the total current drawn from the mains. The power flow has been shown in Figure 5 (green line).

CONTROL ALGORITHMS

The next stage involved developing algorithms for controlling the electric power system during the ride and operation of the machine, taking into consideration various combinations. Due to the similar structure of the power electric circuits of the drilling and bolting rigs, common algorithms were developed for both types of machines.

The P1, P2, and P3 converters were configured depending on the selected operating mode. The appropriate configuration ensures the correct operation of the machine and allows applying appropriate limitations, which guarantees the safe operation of the powered equipment. Particular attention was paid to the configuration of converters cooperating with the bank of batteries. The supervision system was configured to prevent deep discharge of the battery and to ensure optimal charging conditions set by the battery management system (BMS). Depending on the mode (ride or operation), the relevant converters are blocked or configured. After the appropriate machine operating mode has been selected, the configuration of the equipment is performed automatically by the PLC controller, which communicates by means of CAN (controller area network) transmission bus.

Algorithms for Switching on the Supply Voltage

The supply voltage is switched on according to two algorithms, depending on the mode (operation or ride). The main supply voltage is the DC bus voltage for battery operation and the AC voltage when the machine is in the operating mode (drilling or bolting). Before the main voltages are switched on, the auxiliary voltage supplying the circuits of PLC controllers and protection systems is switched on. The converters are configured before switching on the main power.

The algorithm controlling the process of switching on the voltage during the machine ride is shown in **Figure 6**. During the machine ride, a bank of batteries is used as a power source. The unit checks all the systems one by one and prepares them for operation according to the control algorithm. In this mode, the machine must not be connected to an AC power source

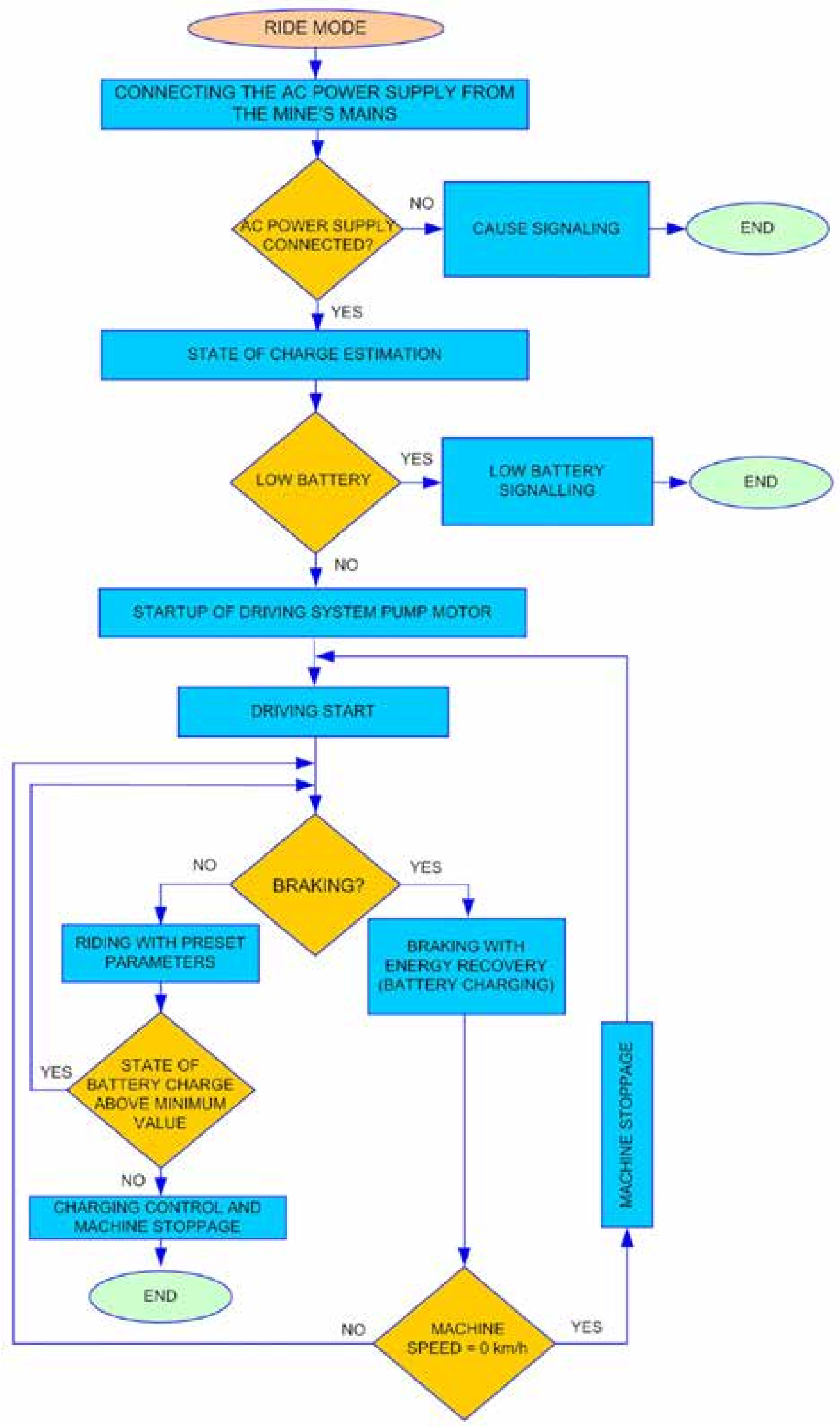


Figure 8: Algorithm controlling the electric power system during the ride.

battery is connected, and the P1 and P3 converters are connected to the circuit. The electrical system is now ready for operation.

Algorithms for Controlling the Electric Power System of the Machine

The algorithm controlling the electric power system is also selected depending on the operation or ride mode. The algorithm during the machine's ride has been shown in Figure 8. In the ride mode, after switching on the voltage, the electric system is ready for riding. The converters (P2, P3) are configured for the ride mode. Before starting a ride, the machine control system checks the state of charge of the batteries. Riding is not possible when the battery is completely discharged. After receiving the command to ride, the control system starts the electric motor of the ride drive. During the ride, the master control system in the PLC continuously monitors the depth of battery discharge. The system informs the operator about the battery discharge status on an ongoing basis. If the critical discharge is reached, the machine must be stopped; otherwise, the battery management system (BMS) will disconnect the battery. Riding cannot be continued unless the battery has been recharged to the minimum value. In most cases, braking of the machine is accompanied by energy return to the battery. In an emergency, when the bank of batteries has been disconnected or the motor is stopped due to a failure of the inverter, the master control system initiates emergency braking using mechanical brakes. The ride (switching on the main motor) is continued when the system is ready for riding, i.e., after the cause of the emergency stop has ceased and the errors are deleted.

via cable, the power cord must not be unwound, and the power supply system must function properly. Before the ride, the battery power system must be prepared.

The algorithm controlling the process of switching on the voltage in the operating mode has been shown in **Figure 7**. In the operating mode, after switching on the auxiliary voltage, the converters (P1, P2, and P3) are configured for work. While the machine is in operation (dr illing, bolting), the mine's AC network is used as a power source. As in the case of machine rides, the power system is first prepared, and its correct operation is checked. In the next step, the

The algorithm for controlling the electric power system during operation is shown in Figure 9. After switching on the voltage in accordance with the procedure described

above, the electrical system is ready for operation. The converters (P1, P2, and P3) are configured for operation. In the operating mode, the state of charge of the battery is constantly monitored by the controller of the master control system. After the work request has been received by the master control system, the motor of the operating system pump is turned on. After the supply voltage has been switched on, the condition of the insulation resistance

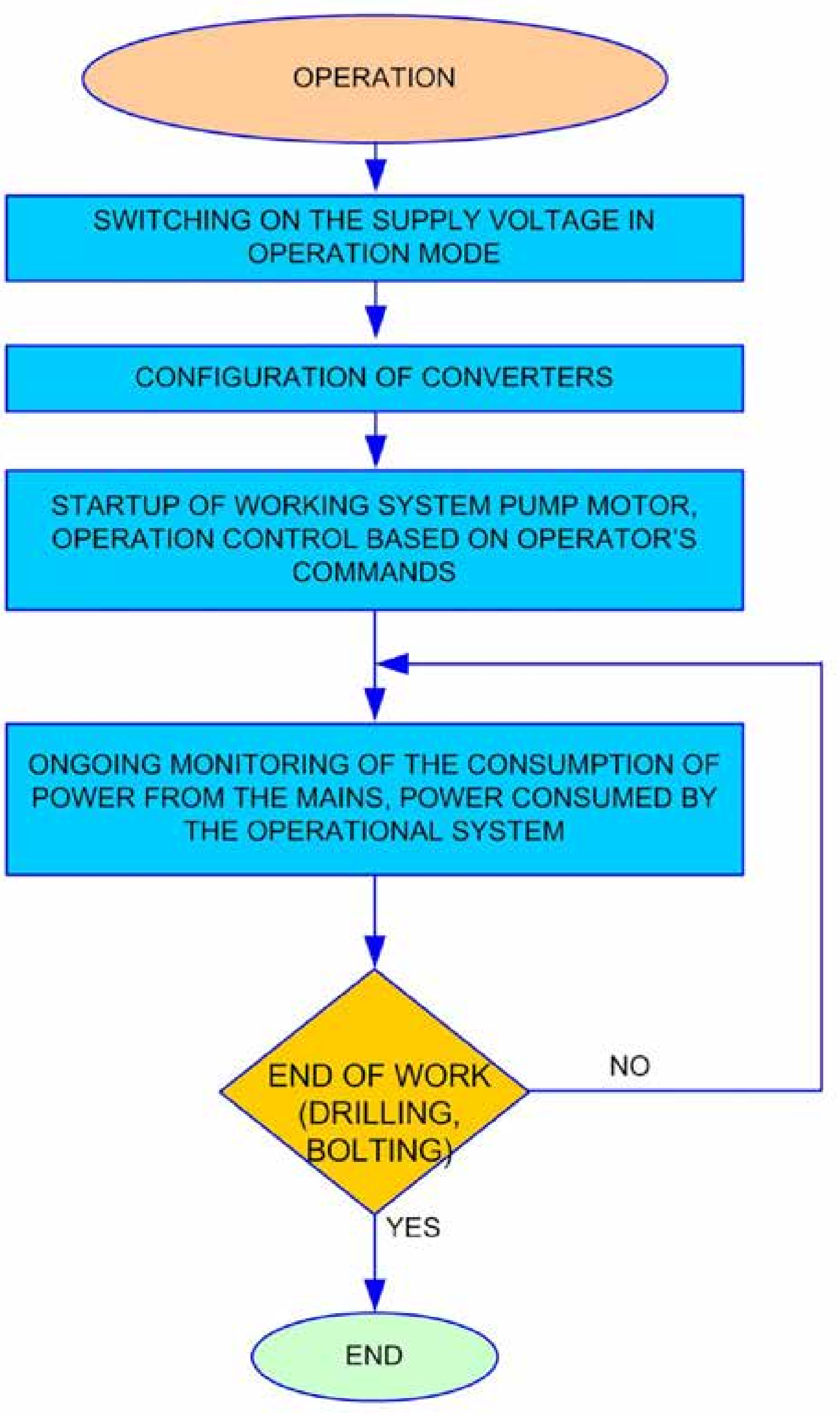


Figure 9: Algorithm controlling the electric power system during operation.

is constantly monitored. If a decrease in resistance is detected, the supply voltage of the machine must be switched off.

VALIDATION TESTS

Laboratory validation tests were carried out for the developed power systems and control algorithms. The tests of the electric drive system of the self-propelled drilling rig and the self-propelled bolting rig in the riding and operation mode were conducted at a special stand in the measuring system shown in Figure 10. The system uses a test platform for PMSM (permanent-magnet synchronous motor), equipped with two synchronous motors coupled with each other, an AC/AC frequency converter with an active rectifier, enabling energy return to the supply network, a PLC logic controller, a switching and measuring apparatus and an operator's panel with a display. The stand with the motors and the operator's desk is shown in **Figure 11**.

The basic element of the system subjected to validation was the DC busbar. The AC/DC converter (P1 diode rectifier), supplied with the voltage of 3 × 500 V from an inductive regulator, is connected to the bus. The P3 DC/DC converter connects the bus with the bank of batteries. The P2 DC/AC converter controls the main drive motor, i.e., the M1 motor.

In order to check the behavior of the system during mains voltage fluctuations, the AC/DC converter (diode rectifier) was supplied with the voltage of 3 × 500 V from an inductive regulator, allowing for changes of this voltage within a range wider than the expected tolerance range of 0.85 ÷ 1.2 UN. The DC bus can be powered during standby/operation and, depending on the connection to the mains, from the AC/DC converter or via the DC/DC converter from the main bank of batteries.

Due to the need to check the behavior of the system at different battery voltage values and during mains voltage fluctuations, the stand was equipped with the M2 motor coupled with the M1 machine motor, which was the loading machine (Figure 10). The main motor load generated by the M2 motor can be regulated by the AC/AC converter controlling the motor, and the value and direction of the torque for any value and direction of rotational speed can be fully adjusted, from positive to negative values. This means that the M2 motor can both load and drive the M1 motor, which allows representing (simulating) the downhill ride and, therefore, motor braking. When driving in a flat area or on a slope, the M1 machine works as a drive motor, drawing energy via the DC/AC converter and the DC bus from the bank of batteries. During drilling or bolting, the vehicle is connected to a 3 × 500 V power supply network, and the M1 machine also functions as a drive motor but draws energy via the DC/AC converter and the DC bus, in this case, from this power supply network. The electric energy generated in the load motor is returned to the supply network via the AC/AC converter. This is the most typical type of operation of the vehicle drive system.

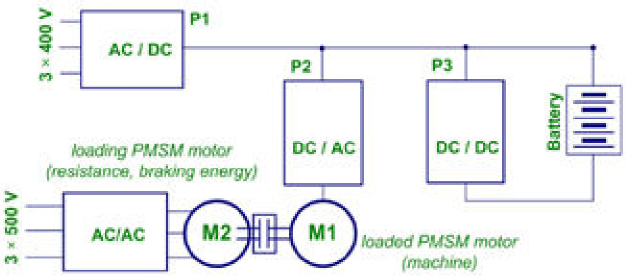


Figure 10: Measuring system for validation tests of the electric drive in the riding and operation mode.

The test of discharging the battery corresponded to long riding with a constant load in the real system. Additionally, it was checked how the voltage at the battery terminals changed as the depth of discharge, and the load increased. The tests were conducted using a battery consisting of six modules connected in series with the following parameters:

- Rated voltage: 499 V;
- Rated capacity: 58.8 Ah;
- Rated energy: 30 kWh;
- Max. voltage: 562 V;
- Nominal voltage: 390 V;
- Max. dynamic discharge current: 120 A;
- Max. dynamic charge current: 60 A;
- Continuous discharge power: 60 kW;
- Continuous charge power: 30 kW.

The battery was discharged by the loading drive in the following system: battery > P3 converter > P2 converter > M1 machine drive motor M1 > M2 loading motor > energy return to the mains 3 × 500 V.

The battery was discharged at approximately 30 kW (half the discharge power) to 35% available energy. Further discharge was blocked by the battery management system (BMS). The conducted tests allowed obtaining battery discharge characteristics (**Figures 12–14**), which enable determining the battery discharge rate, the voltage drop in the state of charge and time function, as well as the amount of load in the state of charge function. A non-linear fitting was performed for voltage changes and a linear fitting for load change so as to find formulas describing these characteristics. An almost perfect match of the functions was achieved. In all the cases, the R-square (COD – coefficient of determination) value is significantly above 0.99. The formulas and matching factors are given in the charts. During the tests, the voltage changed from 504 to 486 V. Reducing the state of charge to 35% decreased the voltage by more than 3%. During battery discharging from 100% to 35%, a load of 37 Ah was consumed. The state of 35% charge was reached after nearly a 42 min operation. The function formula allows calculating that the battery will be completely discharged after 135 min.

Next, tests of charging the bank of batteries were carried out. The P3 charging converter enables full control over the charging current and voltage. However, the basic condition for obtaining the full required charging dynamics is that the voltage of the DC bus must be greater than the voltage of the battery.

Charging tests were carried out in two modes, in accordance with the presented configuration:

- Battery voltage setting mode (energy storage) with the setting of maximum charging current limitation;
- Charging current setting mode with the setting of maximum voltage limitation on the battery.

For the battery voltage setting mode, the preset voltage was the voltage of the fully charged battery: Uzad = Ubat. max = 540 V, and the maximum charging current Imax.ład. = 60 A was set as the charging current limitation. In this mode, charging with the current set by

the battery management system (BMS) was continued until the battery was fully charged (100%). The state of charge is indicated by the BMS of the battery used for battery tests. For the charging current setting mode, the preset current was maximum charging current Izad = Imax.load = 60 A, and the maximum battery voltage Ubat.max = 540 V was set as voltage limitation. The charging current in this mode was also set by the BMS battery management system up to a level of 100%.

Based on the research, it was found that both modes were identical in this case. This is due to the fact that charging parameters are set by the battery management system (BMS), which is the master unit for the charging converter. Therefore, the values of the charging parameters set in the converter are treated each time as acceptable parameters, i.e., limit parameters, which the BMS does not exceed.

Figure 11: Stand for testing the drive system.

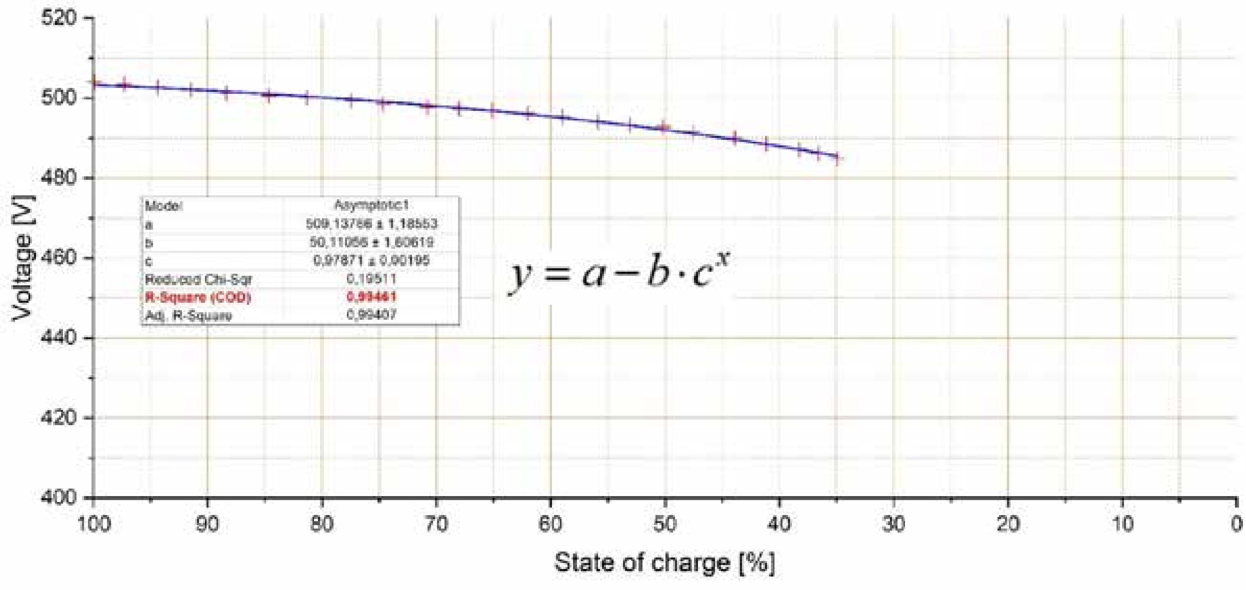


Figure 12: Battery discharge—battery voltage as a function of the state of charge.

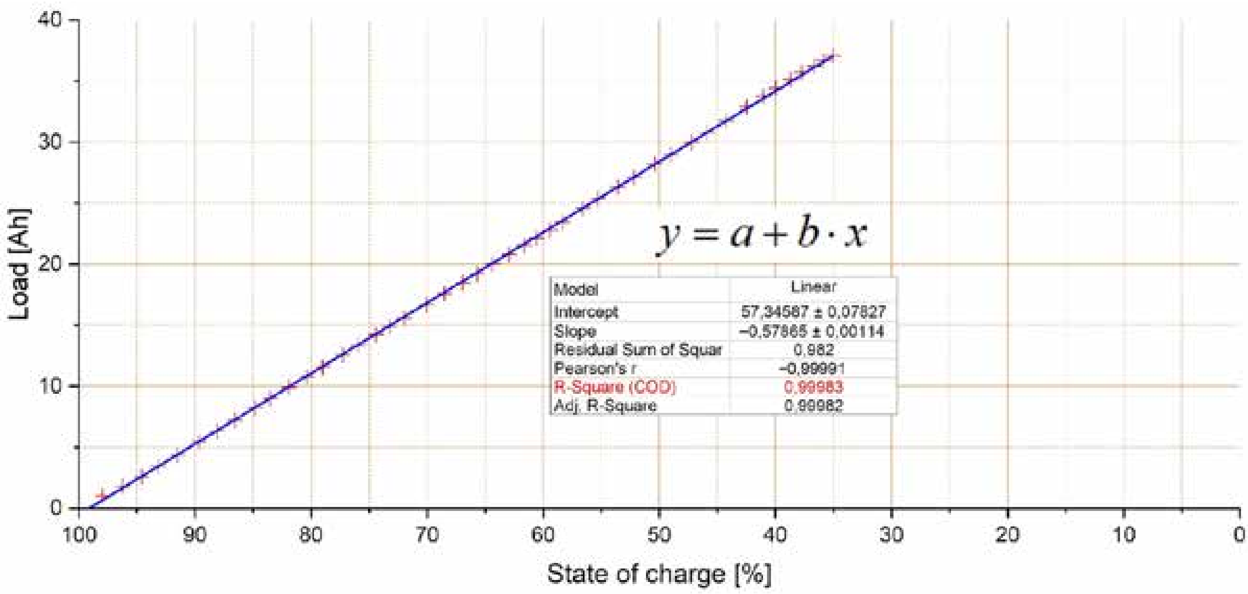


Figure 13: Battery discharge—load as a function of the state of charge.

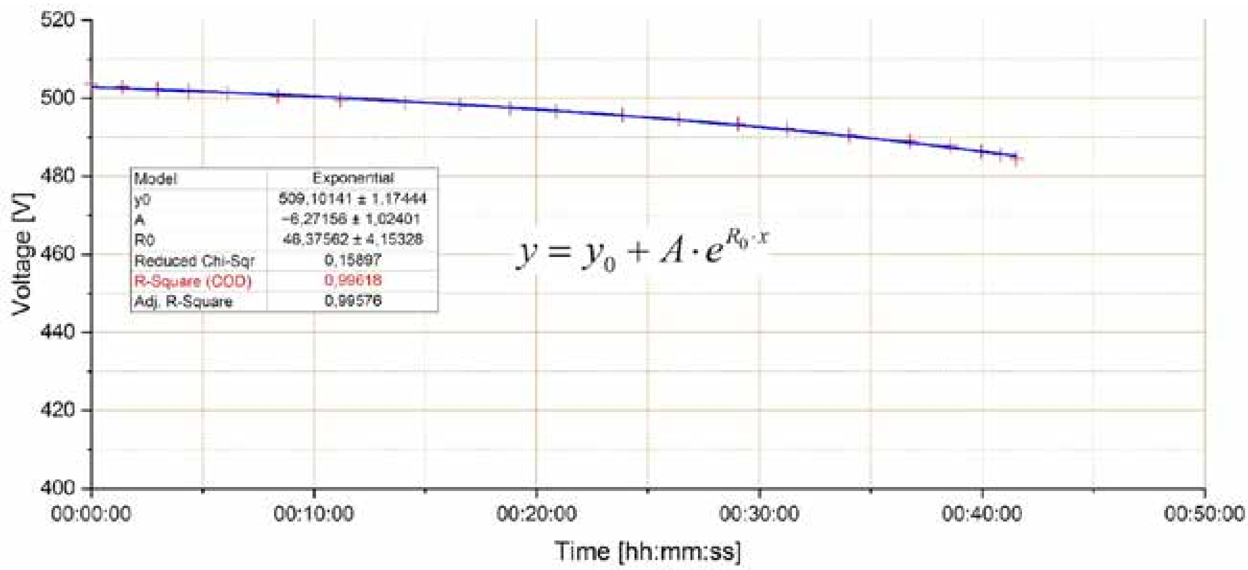


Figure 14: Battery discharge—battery voltage versus discharge time.

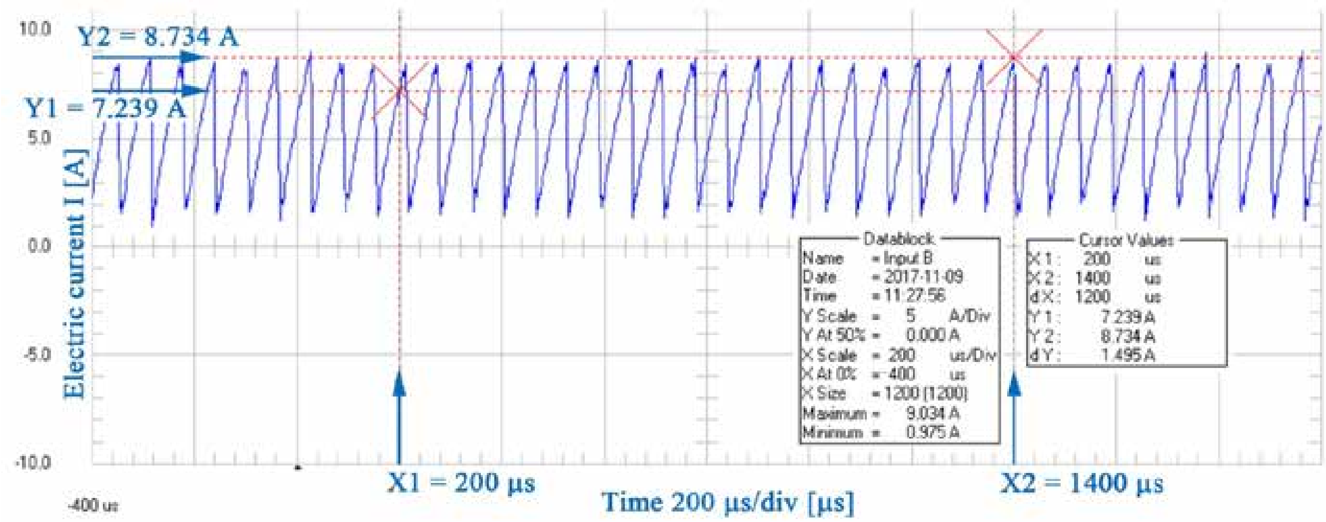


Figure 15: Battery charging current waveform – average battery charging current 5A.

Figure 15 shows the course of the battery charging current. To reduce the current fluctuations around the mean value, it is recommended that a choke with a larger inductance should be used. The inductance of the choke used in the tests was 0.3 mH.

Next, dynamic tests were conducted with battery power and motor load in accordance with the developed system. The dynamic tests involved wide-range changes of the drive motor's loading torque, from the positive to negative nominal value. Therefore, the M2 motor can both load and drive the M1 motor, which simulates riding with recovery due to motor braking. During the simulation of a ride in a flat area or on a hill, the M1 motor works as a drive that draws energy through the DC/AC converter and the DC bus from the bank of batteries. During the battery discharge, there is no possibility of limiting the current drawn from the battery by the P3 converter. However, the current can be limited by the inverter supplying the motor. The tests of the work of the inverter powering the drive motor were conducted in the following modes:

- Speed control;
- Torque control;
- Power control.

Speed control – increasing or decreasing the load (torque) during the drive's operation in the speed control mode causes an increase or decrease in the current and power consumed by the drive system while maintaining a constant rotational speed (to the value set in the converter of maximum current/power, beyond which the speed begins to decrease).

Torque control – increasing or decreasing the load (torque) during the drive operation in the torque control mode causes a reduction or increase in the rotational speed until the driving torque and load torque balance is achieved. The current and power consumed by the drive system also change.

Power control – increasing or decreasing the load (torque) during the drive operation in the power control mode causes a reduction or increase in the rotational speed. The current and power consumed by the drive system also change.

The motor braking tests with energy recovery for the battery involved changing the sign of the torque of the machine loading the drive motor, as a result of which it changed its function from loading to driving, and the tested M1 motor became a generator. The electric power generated in this motor was transmitted through the P2 converter to the DC busbars and, next, through the P3 converter to the BA bank of batteries. The smooth transition of the M2 machine torque from the load torque to the driving torque resulted in a smooth change of the sign of the power drawn from the bank of batteries to power supplied to this battery in the full range of load torque changes. At this point, it should be noted that the above tests were aimed at verifying the functionality of the proposed electric drive system of the analyzed mining machines and not checking the quantitative relationships, all the more so because the tested system was a model one and did not fully reflect the real target system.

The attempt to limit the power consumed by the drive system was aimed at verifying the possibility of limiting the power consumed by the drive system during drilling or bolting supplied from the mains when the power available from the mains is limited to 65 kW. The test was carried out with mains power supplied through the P1 converter. As the P1 converter cannot limit the power consumed, this limitation was effected through the P2 converter supplying the motor. After the drive motor reached the permissible power (limit value), the drive torque was increased while the rotational speed was reduced. This is an advantageous feature of this type of drive as it prevents the tool from jamming in the rock mass. This is one of the standard limitations in converters working as inverters and can be set in a wide range. The test was conducted for the limitation set at 50% motor rated power with a positive result.

The attempt to limit the drive torque by the inverter supplying the drive motor was aimed at checking the possibility of limiting the torque by the drive system during drilling in order to prevent the tool from jamming in the rock mass. The test was carried out with mains power supplied via the P1 converter while increasing the load torque above the set limit torque. In addition, in this case, the limitation was effected through the P2 converter supplying the motor. It is also one of the standard limitations in converters working as inverters and can be set in a wide range. The test was performed for the limit set at 50% rated torque. After exceeding the set torque limit, the speed of the drive motor began to drop rapidly. The result of the driving torque limitation test was positive.

Another attempt to limit the current by the inverter supplying the drive motor was undertaken to check the possibility of limiting the torque by the drive system during operation (drilling) in order to prevent the tool from jamming in the rock mass. The test was carried out with mains power supplied through the P1 converter. Increasing the load torque causes the current of the drive motor to increase. When the limit current is reached, the load current stabilizes, and the rotational speed is reduced, which should prevent tool jamming. In addition, in this case, the limitation was effected through the P2 converter supplying the motor. It is also one of the standard limitations in converters working as inverters and can be set at any level. The test was performed for the limitation set at 50% rated current. After exceeding the set current limit, the speed of the drive motor began to drop rapidly. The current limitation test was positive.

CONCLUSIONS

Wherever machines powered by internal combustion engines are used, attempts are undertaken to replace them with electric equipment. In the case of many working machines and vehicles, the mains supply does not allow them to be fully operational; hence, it is necessary to use a battery power supply. It is crucial for every working machine that its battery-powered version meets the same requirements as the one powered by the combustion engine. Therefore, the requirements in the target place of work in terms of battery power must always be specified. Underground mining is characterized by difficult working conditions and requirements that do not allow implementing solutions applied in other industries. Conditions in underground mines are so diverse that it is not always possible to develop universal solutions and machines.

The aim of the works described in this article was to determine and describe the operating states of the machine as well as to develop power systems and control algorithms that enable work in all operating conditions occurring in the analyzed mine. After the basic operating states of the machine had been described, the algorithms for controlling the electric power system were determined. In simple words, it comes down to the states of charging and discharging the battery under various possible conditions. The abovediscussed algorithms for switching on the main voltage, riding, and operation set control over the converters and other elements of the electrical system so as to enable work with electrical parameters corresponding to the rated data of the designed machine. Next, the algorithms were checked during simulation tests and in the real electrical system. The system was based on the currently available elements, but its configuration corresponded to the layout of the designed machines. The developed concept, taking into account the control method, was tested in a model system with properties similar to the actual power supply system of the target machines. Machine operating states, such as riding, braking during ride and operation, were checked and verified. The validation proved the correctness and effectiveness of the power systems and control algorithms, which were then implemented in the designed machines. The developed and tested self-propelled electric bolting rig Roof Master RM 1.8KE and the drilling rig Face Master FM 1.7LE are the best proof that the works were performed properly. These are the first fully electric and battery-powered machines in Poland that have been designed and manufactured for the conditions of KGHM S.A. Battery-powered machines are the inevitable future of mining, which is also being created by Polish research units and Polish companies.

The drilling and bolting rigs are based on the above-presented power systems and control algorithms, which makes them unique on a global scale. The applied power systems and control algorithms are universal enough to be implemented in two different types of machines. Both machines were specially designed to substitute diesel machines in the conditions of a Polish ore mine. They are the lowest underground battery-powered drilling and bolting rigs with onboard chargers. Additionally, the machines can also be charged using external fast battery chargers. Machines offered by other manufacturers are much higher, above 2 m, which is not a challenge. Despite the low height, the presented machines' operation time without charging is similar to that of competitor products. Their limitation lies in the fact that they can work successfully only in approximate conditions in terms of user requirements and underground power grid parameters. However, some modifications can be made to adapt the presented machines to different conditions.

The next step is to develop power systems and control algorithms. There are two major directions. The first is to increase the working time without charging, whereas the second is to enable charging not only in gaps between drilling or bolting but also at the time of machine operation. There are also some general problems to be solved, for example, how to reduce the consumption of energy needed for riding as well as drilling and bolting processes.

Please note that references and reading can be obtained using the following link: ???